NUCLEAR ENGINEERING VOL. 4 NO. 39 JUNE, 1959

Euratom Appraisal

ALTHOUGH the first hurdles in the path of Euratom have been safely negotiated, there are still many problems to be faced. Indeed, quite a number of people are prepared to expound on these problems at great length, and suggest that either they are incapable of solution or alternatively that the necessary compromise will render the organization impotent. The evidence to dispute this view mounts daily as Europe becomes more "European" minded.

One of the impressive aspects of Euratom is its willingness to recognize these problems and appreciate that differing and often opposed interests may not easily be satisfied. In this awareness, and in its flexibility of approach, lies the strength of the organization. If the present Euratom Commission were to adopt an autocratic attitude and attempt to force preconceived policies on the member states, then it is likely that strong opposition would be met and the ultimate authority of the Commission weakened. Those who regard flexibility as evidence of ineffectiveness, should consider the achievements of Euratom in its 18 months existence which include the setting up of a complete administration, the negotiation of two treaties—pacts with Brazil and Canada are also nearly complete—and the production of radiation handling regulations.

Staffing

Doubts have been expressed on the ability of Euratom to recruit staff of adequate strength and experience, not only to man its research establishment but also to represent Euratom on its various co-operative and development projects. The contention is that member states already have considerable recruitment difficulty, and they will be reluctant to hand men over. Euratom itself does not see the problem in this light and emphasizes that the distinction between employment by (say) a country's atomic energy commission and by Euratom is of little importance. Sceptics ignore the prestige that is attached to the representation of an international body and the opportunities that arise, particularly in the early days, for establishing personal reputations.

At the present time, Euratom has no fixed ideas on what will constitute its technical strength over the next few years and is prepared to adjust its thinking from month to month. With such projects as Dragon, invitations will be sent to companies and commissions to attach personnel to the project under Euratom auspices. Specific employment by Euratom is deemed a matter of administrative convenience only. Such staff would, however, be expected to return to a central organization under Euratom for some period, at present undetermined. Whether these returning, experienced men should set up Euratom design teams is also yet to be decided.

The problems of adequately serving and guiding organizations that on the one hand, as in France, are predominantly government controlled, and on the other hand, as in Germany, predominantly private enterprise are recognized as serious but not considered to be insuperable. The general principle adopted is that the government organizations are regarded as separate from the political Government of the country and are treated on the same basis as large individual groups. It is recognized that this can only be a rough principle, and that the contribution of, for example, CEA is much greater than that of a single company. But, so also is the influence, and, provided the existing determined co-operative spirit can be maintained, an effective balance can be struck.

Patent Problem

In the same way it is recognized that the values of patents in France and Germany are very different, and whilst the French Government can specify in a treaty, rules covering atomic energy patents in France, as they are largely owned by the CEA, the German Government cannot do the same. It is to Euratom's advantage here that development in Europe is less advanced than in America and in England, as existing patents are likely to cover largely obsolescent equipment, and future patents will be drawn up with Euratom an existing organization. Many will stem from Euratom sponsored or controlled development programmes and, as time goes on, the complication introduced by contrary French and German systems will diminish rather than increase. The re-negotiation of the patents section of the U.S.-Euratom treaty may also establish valuable precedents.

In the co-ordination of health and safety regulations Euratom has already made a significant start. Regulations covering the handling of sealed and unsealed sources have been published and although these may be substantially the same as those recommended in the IAEA report they are more comprehensive in scope and do represent an international decision which will be implemented. In this particular field of health and safety, Euratom's powers are somewhat exceptional, in that although in general it is an advisory organization,

safety recommendations can only be neglected by a country at the risk of creating an international situation.

U.K. Relationship

It is of considerable importance to the U.K. that Euratom regards the recently negotiated U.K. agreement as an enabling pact holding the potential for valuable and amicable co-operation. Twelve months ago the relationship between the U.K. and Euratom could at best be described as cool, but a considerable improvement has taken place and it is to be hoped that every effort will be made to ensure that cordiality is encouraged and not suppressed. The Foreign Office were required to conclude the co-operation agreement but the implementation of the clauses is the responsibility of the AEA.

Euratom is appreciative of the fact that this country cannot afford to subsidize European power development programmes, nor does it expect, or look for, non-reciprocal favours. It is, however, anxious to receive official recognition and to see properly opened, channels of communication. There are signs that the AEA is now prepared to go much further in taking Euratom into its confidence, although there is still evidence of Foreign Office suspicion. As a first move the Government and the Commission have agreed to set up a "continuing committee" and the AEA has appointed a permanent representative to be attached to the ambassador in Brussels.

Understandably the Authority is anxious to avoid the necessity of setting up a number of formal collaboration committees in various branches of the nuclear energy field. These are both time consuming and not necessarily productive; for example, Britain sits on several international committees on health and safety and the time and effort expended by senior people on travelling, meetings and paper work are reaching unreasonable proportions.

We feel, however, that Euratom is also keen to eliminate waste, and whilst no doubt it would appreciate a formal declaration of collaboration on a specific subject such as health and safety, once given the assurance that the subject was completely unclassified —not only from the military standpoint, but also from any supposed commercial and political standpoints— then co-ordination could be left to the individuals directly concerned.

It would be too much to expect the AEA to welcome Euratom into a project as immediate as the AGR and certainly strong resistance would be met from a number of the industrial groups. Some are beginning to appreciate the advantages of sharing, and the hollowness of superiority in isolation, but this philosophy is not generally acceptable. The fast breeder system has, however, no immediate commercial potential and we could well invite a team from Euratom to become attached to the Dounreay team, while the introduction of new backgrounds into the fast reactor programme would be to the general good.

From a commercial standpoint, both sides would greatly benefit from a more frank exchange on fuel element performance and from an offer of attractive burn-up guarantees which would allow potential owners to plan ahead. At present it would be a brave director who recommended to his board the adoption of a British reactor, without a full fuel guarantee in view of the Euratom-U.S. agreement—and sneers about subsidization do not help—and the tremendous prestige and technical weight that the joint U.S.-Euratom development programme implies. There are signs that in negotiations with Japan (and we do not suggest that Japan should be given less favourable terms than Euratom) a more realistic offer was made than in the SENN tender, but commercially and politically it would be better if the impression could be given that the Authority was promoting co-operation and confidence rather than that it was sitting back until forced to make a move.

Impressive Nuclear Ship Proposals

THE variety and quality of the feasibility studies that have been presented to the Admiralty during the past month demonstrate the virility and ingenuity of the British nuclear energy industry. Few people who have had the privilege of examining the designs have not been impressed, and although the criticism can so easily be made that feasibility studies always look attractive, there is little doubt that a great deal of valuable thought has gone into their preparation.

The designs submitted range from systems which are already developed to long-term projects which are contemporaneous with the third generation of land-based plant. Of the eight designs submitted, four are based on essentially American developed technology, three on traditional British gas cooling and graphite moderation and one breaks completely new ground with steam cooling and heavy water moderation.

In addition to a novel coolant, Vickers have also proposed a novel circulator and a novel control system. The use of the thermo-compressor for primary coolant circulation (a process which traditional thermodynamicists at first sight declare impossible) opens up an exciting new field of development.

In our editorial last month we made suggestions as to how a ship project could be financed and organized. We pointed the dangers inherent in Admiralty-AEA control, particularly with regard to dissemination of information. We have seen interesting demonstrations of this failing over these studies. Although the companies were finally permitted to make known as much about their designs as they wished—and it was after all their money that was spent—it was only after a week of changing policy. Even then the Admiralty claimed as officially secret the nature of the ship for which the propulsion units were devised and the AEA refused to disclose any information about its own study. At this stage of the proceedings we can afford to be amused but later on it can be a serious matter.

DIGEST...

Surveying Significant News

Industry and the AEA Present Nuclear Ship Studies

Studies of nuclear ship propulsion units conducted by the AEA, and seven U.K. engineering firms, have been presented, under arrangements made by the Admiralty and the AEA, to the Board of Admiralty, Admiralty Naval and Civilian Staff, the Ministry of Transport and Civil Aviation and other Government Departments and to the Marine Nuclear Propulsion Committee. The project was organized to inform British shipbuilding and marine engineering interests on the present state of technology and the prospects for economic ship propulsion. The eight reactor systems will now be studied by the AEA and Ministry of Transport and Civil Aviation and the claims made by each will be assessed by a technical sub-committee which will be set up by the Civil Lord's committee. This committee will have at its disposal the critical assessment made by the Yarrow Admiralty Research Department.

IAEA Fuel Agreements with U.K., U.S.A., U.S.S.R.

Final agreements with Britain, the United States and the U.S.S.R., have now been signed by the International Atomic Energy Agency for the supply of nuclear fuels. This now creates a new basis for one of the most important functions of the agency, viz., the supply to member states of fissionable materials for peaceful purposes. According to the director-general of the agency, the IAEA now has at its disposal 5,100 kg of uranium 235.

Valuable OEEC Conference at Stresa

More than 500 European industrialists recently spent a week in Stresa, Italy, discussing ways and means of hastening the exploitation of nuclear energy in the 17 countries which contribute to the Organization for European Economic Co-operation. A report of the proceedings begins on page 270 of this issue.

BSI Reviews Second Glossary Draft

Several hundred suggestions have been received by the British Standards Institution for amendments to the Glossary of Terms Used in Nuclear Science, the second draft of which B.S.I. completed on March 20. The first incomplete draft was circulated in mid-1957 and the Institution anticipate that a further 18 months' work is required to complete the manual.

Rolls-Royce Manufacture Fuel Elements

In answer to Opposition queries the Prime Minister, Mr. Macmillan, has confirmed that Rolls-Royce will be producing reactor fuel elements for nuclear submarines (*Nuclear Engineering*, April, 1959, p. 149). Rolls-Royce and Associates are responsible for the installation of the American Westinghouse reactor in the nuclear powered submarine, *Dreadnought*. The installation of the reactor is but part of the programme as refuelling is likely to concern Rolls-Royce for many years in the future.

Gas-cooled Reactor for Oak Ridge

A $30 million experimental gas-cooled reactor is to be built at the Oak Ridge National Laboratory. Designated the EGCR the reactor will probably be located at Clinch River, south east of the Laboratory. It is expected that a turbogenerator having a capacity of 25 MW will be attached to the reactor for power production. EGCR will be a versatile experimental reactor for advancing along a broad front the technology of gas-cooled power reactors, with particular reference to fuel elements, materials and components and different types of gas coolants. The reactor will be the largest yet constructed at Oak Ridge.

Health and Safety Courses

Following recommendations made by a Committee on Training in Health and Safety under Sir Douglas Veale, two courses will be run at London University starting in October for science and medical students. The need for a national training centre is under discussion.

U.K.-Euratom Continuing Committee Founded

The U.K.-Euratom agreement, signed on February 6, has been carried a step further by the establishing of a committee to supervise the operation of the agreement. The committee will consist of a U.K. Minister (Mr. R. Maudling) and the Chairman of the AEA (Lord Plowden) and the Chairman and another member of the Euratom Commission. They will be assisted by a technical committee and their purpose will be to provide a forum for consultations on matters arising out of the applications of the agreement and for discussions on additional arrangements.

Industry and Utilities Discuss U.S.-Euratom Agreement

A meeting attended by more than 30 producers of electricity and 50 representatives of concerns interested in supplying equipment for nuclear power stations has discussed several problems in connection with the U.S.-Euratom agreement. Main purpose of the meeting was to evaluate ways of using the loan of $135 million from the U.S. at a moderate rate of interest, the contributions of $50 million each from the U.S. and Euratom to the development of research, centred on types of reactor included in the programme and implementing the U.S. guarantees for the supply and cost of fuel, the resale of plutonium, and the reprocessing of used fuel.

NRU's High Load Factor Despite Heavy Water Leakage

Canada's 220 MW materials testing reactor NRU has obtained more than 90% utilization this year. NRU has been operating at full power since December 8, 1958. A leakage of heavy water amounting to ¼ ton per day is not affecting operation. The leakage—from the vessel to the J-rod annulus—is either through a faulty weld or through the upper ring seal between vessel and top header. Near this point there is a simultaneous leakage of light water from several cooling circuits. Total daily loss of both heavy and light water is about 2,000 lb: the D_2O is subsequently recovered and returned. Repairs will be effected during a forthcoming 4-week shutdown for the installation of two loop assemblies.

SELNI PWR Project to Go Ahead

Westinghouse Electric have now received a definite order following the letter of intent first placed in December, 1956, for the supply of a nuclear steam generating plant to Societa Elettronucleare Italiana of Milan. The 160-MW reactor will be of the pressurized water type and is referred to as the Enrico Fermi Nuclear Power Project (not to be confused with the fast breeder project at Monroe, Michigan); it will be located in northern Italy. It is scheduled to go critical early in 1963. The plant is to operate on a base load basis and will provide electricity to the Edison Group network, the largest privately owned utility in Italy, and additional utilities in northern Italy. A significant proportion of the component equipment is to be manufactured in Italy.

DSIR Report Outlines Expansion Plans

The 1958 DSIR report, recently published, is essentially a record of action, already taken or contemplated, in view of the second five-year plan (1959-1964). A programme has been evolved entailing an expenditure of £61 million compared with £36 million in 1954-1959, the period of the first five-year plan. All spheres of the Department's activities, in particular, policies governing grants, will benefit. The scope of the research establishments has been re-defined and improved facilities have been created to establish closer liaison with industry. A new departure is a plan for adopting good ideas originating in companies of restricted financial capacity, for further development. The Department's active interest in nuclear physics is substantial. Inter alia, expenditure allocated under this heading provides for the maintenance, operation and development of large particle accelerators at six British Universities. The Overseas Liaison Division, responsible for the U.K. contributions to European Nuclear Research, spent £1,100,000 during the past fiscal year.

GE's Materials Testing Reactor Critical

General Electric's 30-MW test reactor (GETR), the first privately financed materials testing reactor in the U.S. and labelled " licence No. 1," has diverged. Its operation will mean a substantial increase in the American programme for irradiation testing of fuel. The facilities are being marketed to organizations requiring radiation testing in their research and development programmes, and to the chemical, metal, petroleum, electronics, aviation, plastics and rubber industries as well as the nuclear industry.

SHIP PROPOSALS

The results of eight feasibility studies on nuclear propulsion systems were submitted to the Admiralty during the week beginning May 4. Seven of these had been prepared by industrial organizations and one by the U.K.AEA. The Admiralty, the Ministry of Transport and Civil Aviation, other Government departments and the Marine Nuclear Propulsion Committee were able to hear lectures on the proposals and could examine models of the designs.

(Translations, page 262)

A.E.I.—John Thompson Nuclear Energy Co., Ltd.

The propulsion system submitted by the A.E.I.-John Thompson Nuclear Energy Co. included a reactor of the boiling water type. The design is the result of the company's collaboration with General Electric of America who have played a leading part in the development of the BWR in the U.S.A. It is estimated that a complete unit could be delivered in 30 months for which certain core components would be purchased from GE. Principal advantages claimed for the system are its simplicity, its light weight, its ability to burn plutonium, and, due to the absence of heat exchangers, compactness.

In addition to operating the VBWR at Vallecitos, General Electric is currently building the Dresden nuclear power station; fuel elements for this station are described in this issue of *Nuclear Engineering* on pages 253-258. Fuel elements for the ship reactor can be expected to correspond closely with them.

An interesting departure from normal practice is the proposal for a banded pressure vessel. Results of tests made on scale models by John Thompson were first reported a few months ago (*Nuclear Engineering*, January, 1959, page 35).

A fuel burn-up of 10,000 MWd/t is envisaged corresponding to 380 days at full power; refuelling would occupy approx. 100 hours and require a maximum lift of 35 tons.

A.E.I.—J.T. Design

Reactor type	BWR
Output (50% full load)	82 MW(t)
Operating pressure	1,000 p.s.i.g.
Top temperature	286°C
Core size	72.5 in. × 62 in. dia.
Fuel	UO_2
Initial enrichment	2.1%
Reject enrichment	1%
Total investment	8.7 tonnes
No. of fuel channels	104
No. of elements/channel	36
No. of rods/element	3
Canning	0.033 in. Zircaloy
Maximum fuel temp.	2,000°C
Maximum can temp.	300°C
Primary control	s.s. clad boron steel
Secondary control	boron solution
Pressure vessel type	banded
Pressure vessel dim.	30 ft × 8 ft i.d.
Containment	55 ft × 38 ft dia.
Shell thickness	2½ in.
Total wt.	1,600 tons

Babcock and Wilcox Design

Reactor type	PWR
Output	180 MW(t)
Fuel	UO_2
Cladding	Zr or s.s.
Enrichment (s.s.)	4%
Enrichment (Zr)	2%
Fuel charge	(approx.) 9 tons
Operating pressure	1,750 p.s.i.
Evaporation	616,000 lb/h
Turbine steam pressure	410 p.s.i.
Steam temp.	447°F
Containment vessel	Spherical
Vessel dia.	42 ft 6 in.
Total wt. of plant	3,000 tons

Babcock and Wilcox, Ltd.

Through their association with Babcock and Wilcox, of America, the British Babcock and Wilcox have been able to gain direct experience of the various pressurized water projects that the American company has undertaken including the N.S. "Savannah" featured in *Nuclear Engineering*, May, 1958, pages 197-199. Basically similar to the "Savannah," the PWR proposed has a power output 2½ times as large while occupying only 20% more space. The company points out that the PWR is the basic system adopted for all nuclear ships to date and is probably the most developed compact reactor in the world at the present time.

Either stainless steel or zirconium is proposed for the cladding and structure of the reactor core, the enrichment of the fuel in the two cases being 4% or 2%. One fuel charge is sufficient for 500 days' operation at full power corresponding to a normal service of two to five years. It is expected that ultimately all necessary facilities for fuel element manufacture will be available in Great Britain when the cost for fuel will lie between 0.3d. and 0.6d./s.h.p.h.

De Havilland Engine Co., Ltd.

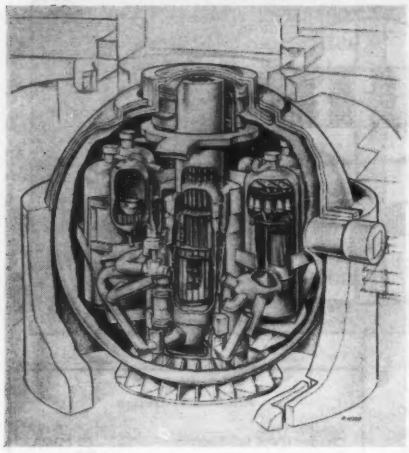
Recognized as a long-term project, the de Havilland design is based upon the high-temperature gas-cooled reactor system which is under development by the AEA at Winfrith Heath in association with OEEC and termed the Dragon project. The company believes, however, that a full-scale effort initiated at the beginning of 1960 would permit the launching of a prototype ship by the end of 1964.

The company has already gained practical experience in the design and construction of loop circuits and has a background of experience in high-temperature gas technology. Twin reactors are proposed, each capable of operating independently; the fuel would be a mixture of uranium and thorium carbide bonded into graphite pellets and contained in sealed impermeable graphite blocks. The boiler circulator units are integrated with the pressure vessel which results in a compact plant layout and enables the secondary containment vessel to be fitted into the main biological shield; no additional shielding is necessary to protect against leakage into the secondary containment.

An estimate of the cost of the first production unit, less core fuel blocks, indicates a figure in the region of £1.4 million for a twin reactor installation and, although high enrichment fuel is necessary, the low investment somewhat mitigates its high cost. Although a steam circuit is envisaged in a first design the company looks towards the use of gas turbines and an all-beryllia moderated core, should the use of an active primary circuit appear permissible in the future.

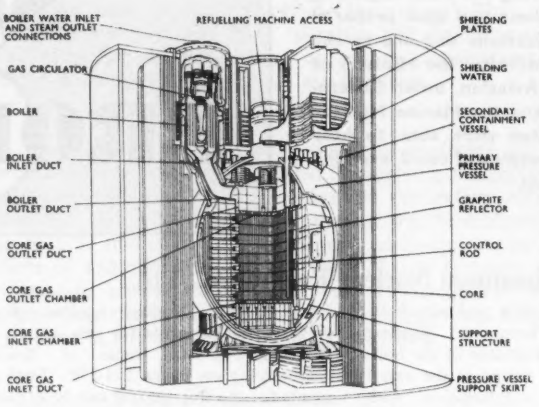
De Havilland Design

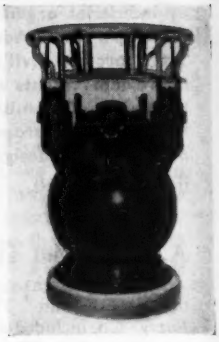
Reactor type	HTGC
Output (2 reactors)	150 MW(t)
Coolant	Helium
Fuel	Carbides of U^{235} and Th
Moderator	Graphite
Core dimensions	6 ft × 6 ft dia.
Graphite reflector	2 ft–2½ ft
No. of fuel columns	1,729
No. of blocks/column	9
Initial U enrichment	90%
Total wt. of uranium	67 kg
Total wt. of thorium	674 kg
Centre channel rating	101 MW/t
Average burn-up	65,600 MWd/t
Coolant pressure	735 p.s.i.a.
Inlet temp.	200°C
Outlet temp.	700°C
Max. fuel temp.	1,500°C
Max. graphite temp.	900°C
Reactor pumping power	530 kW
Steam temp.	850°F
Steam pressure	600 p.s.i.a.
Total wt. (2 reactors)	2,400 tons
Overall height	25 ft
Overall dia.	25 ft 4 in.



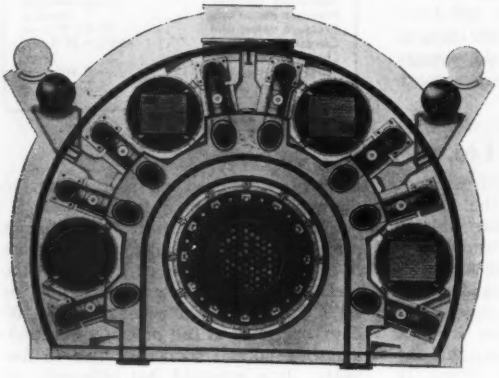
(Above) Babcock and Wilcox PWR.

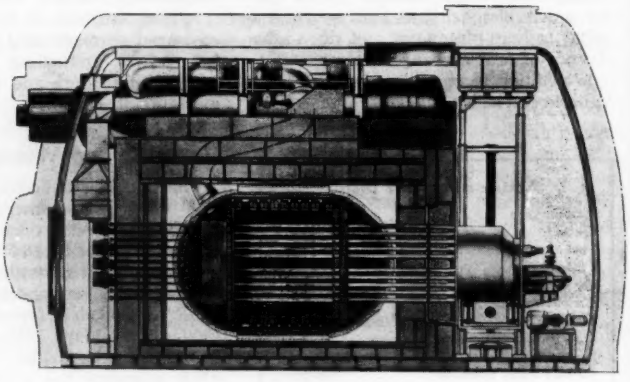
(Below) Cut-away section and (right) model of De Havilland's HTGC.



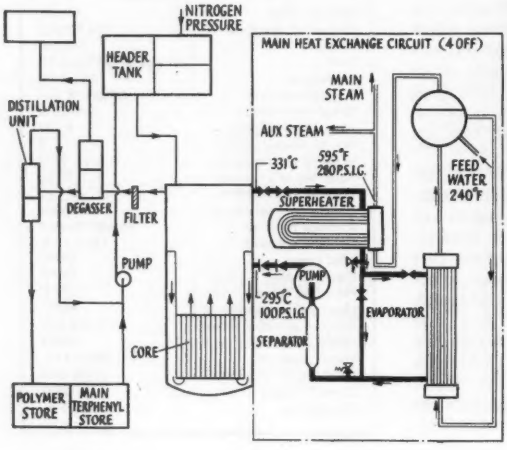


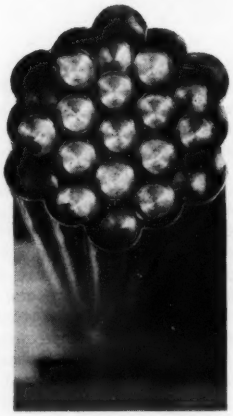
(Below) Sectioned side and end elevations of the G.E.C. gas-cooled graphite-moderated reactor design.

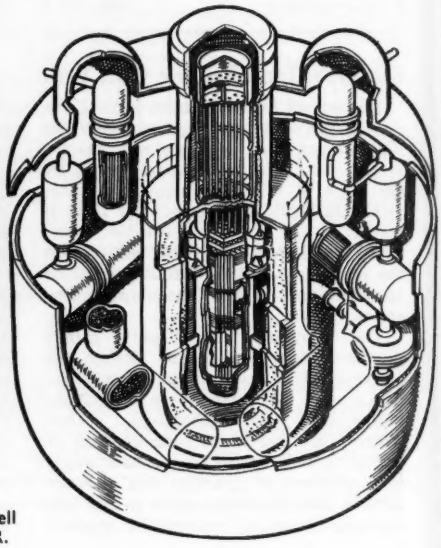




(Below) Flow sheet of the Hawker Siddeley organic-moderated reactor with (right) an end view of a fuel element.







(Right) The Mitchell consortium's PBWR.

General Electric Atomic Energy Group

Continuing in their gas-cooled graphite-moderated reactor tradition, G.E.C., Simon-Carves have submitted a design for a 150 MW unit, which in size is approximately the same as one of the charge/discharge machines at Hunterston. The much greater specific power rating of the reactor has been made possible by a revolutionary fuel element design the details of which the company is keeping secret. It is known, however, that the fuel is uranium dioxide and the canning stainless steel, and the elements are provided with graphite sleeves.

The graphite core is made of blocks held together by an enveloping steel structure and is laid with the fuel channels extending horizontally through the core, interspersed with control rod channels, also horizontal. The pressure vessel is a cylindrical vessel with domed ends and the charge/discharge stand pipes are at one end with control rod emergency access pipes at the other. Although shielding in the main is steel and water concrete plugs are used at the charge/discharge end of the stand pipes.

Four steam raising units are mounted symmetrically around the reactor and provision is included over the reactor structure for generation of CO_2 from bunker fuel. This plant is located outside the containment vessel, a truncated horizontal cylinder resting on a grill.

G.E.C. Design

Reactor type	GCGM
Output	150 MW(t)
Fuel	s.s. clad UO_2
Element sleeves	graphite
Maximum can temp.	675°C
Core dimensions	6.75 ft × 7.5 ft dia.
Coolant	CO_2
Inlet gas temp.	475°F
Outlet gas temp.	990°F
Circulator drives	Turbine
Pressure vessel i.d.	14 ft
Pressure vessel wt.	125 tons
Support grid length	56.5 ft
Support grid wt.	200 tons
Steam temp.	850°F
Steam pressure	600 p.s.i.
Steam raising units	4
Boiler dia.	7.5 ft
Containment vessel wt.	243 tons
Total wt.	2,400 tons

Hawker Siddeley Nuclear Power Co. Ltd.

The Hawker Siddeley Nuclear Power Co. has proposed a propulsion system incorporating an organic moderated reactor, which has been developed to date largely by Atomics International of U.S.A. The organic reactor offers the promise of lowest capital cost/s.h.p. due to the relatively low pressure in the reactor vessel and the use of mild steel piping throughout in the construction. Higher operational temperatures are envisaged than exist in OMRE and oxide fuel with stainless steel canning is proposed.

Replacement cost for the degraded terphenyl moderated coolant is calculated to be 0.07 d/s.h.p.h.

An OMR system designed for an output of 17,000 s.h.p. would cost under £900,000 and weigh about 1,300 tons, which would indicate an operating cost for a 40,000 ton tanker of about 5% higher than with conventional fuels. Considerable development potential is envisaged including the use of beryllium canning, a graphite reflector and the adoption of a two zone core in which the high-temperature coolant is used for superheating. Steam conditions of 710° F and 480 p.s.i.a. are predicted.

Hawker Siddeley Scaled-down Design

Reactor type	OMR
Output	56 MW(t)
Coolant	Terphenyl
Operating pressure	<100 p.s.i.
Fuel	s.s. clad UO_2
Enrichment	1.4%
Core dimensions	5 ft × 5.2 ft dia.
No. of fuel elements	264
No. of rods/element	19
No. of primary loops	2
Bulk inlet temp.	295°C
Bulk outlet temp.	331°C
Outer outlet temp.	405°C
Steam temp.	710°F
Steam pressure	480 p.s.i.a.
Cycle efficiency	24.8%
Total wt.	1,300 tons

Mitchell Engineering Consortium

The group of companies formed by Mitchell Engineering, Fairfield Shipbuilding and Engineering, and Combustion Engineering has proposed a design based upon their background of pressurized boiling water technology stemming from the collaboration between Mitchells, AMF and GNEC. The proposed system is based on the closed cycle BWR with four heat exchanging loops and pumped circulation. Circulation in the core is upwards and an average of 7.3% steam voids in the core is expected.

Two types of fuel element would be used, those with natural uranium being placed at each corner of the fuel assemblies to control hot spots caused by the high flux in the water channels outside the boxes. Three types of control rod are proposed, the centre rod being of hafnium, the four surrounding rods of 60% hafnium remainder boron stainless steel, and 16 scram rods of boron stainless steel. The control rods are actuated from the top of the vessel through 21 6-in. pipe thimbles approximately 9 ft long.

The pressure vessel is clad in stainless steel and two concentric thermal shields of stainless steel are provided, the outer being 2 in. thick and the inner 1½ in. thick. Each of the four primary coolant loops includes a separator lined with stainless steel; the condenser heat exchangers are of the concentric tube type. Containment is based on a maximum incredible accident yielding 104 p.s.i. pressure rise in the vessel.

The design permits operation at 80% full power for a period of 3½ years, although to obtain uniform burn-up of fuel in the core shuffling of the fuel elements should take place at 12- or 15-month intervals during refit. The fuel elements cannot be changed at sea.

Mitchell Engineering Design

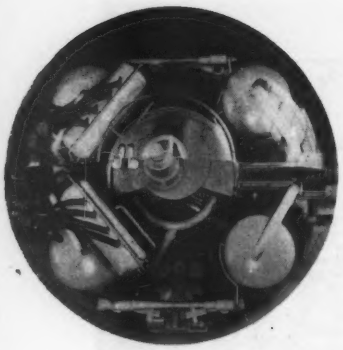
Reactor type	BWR
Output	156 MW(t)
Fuel natural and enriched	UO_2
Enrichment	2.55%
Burn-up	11,000 MWd/t
Core dimension	94 in. × 82 in. dia.
No. of fuel assemblies	216
No. of rods/assembly	56
Length of rods	8 ft
Cladding	s.s 0.366 in. i.d., 0.15 in. wall
No. of control rods	24
Shape of control rods	cruciform
Pressure vessel	23 ft 10 in. × 9 ft i.d.
Material	0.2 in. s.s. clad, 4 in. carbon steel
Primary coolant loops	4
Coolant pressure	950 p.s.i.a.
Top temp.	538°F
Flow	14,000,000 lb/h
Secondary coolant pressure	650 p.s.i.a.
Secondary temp.	496°F
Flow	534,000 lb/h
Feed water temp.	240°F
Shielding, borated water also sideways	3 ft 6 in. thick 8½ in. s.s., 7 in. water, 15 in. steel, 1 in. lead
Containment design pressure	130 p.s.i.g.
Dimensions	50 ft 2 in. × 46 ft i.d.
Material	mild steel, SA 212B

AEA

The AEA has been considering the application of the advanced gas-cooled reactor to marine propulsion but at the present stage is unwilling to disclose its conclusions. It is understood that the essential characteristics of the reactor are not dissimilar from the experimental model being built at Windscale but that the results of the feasibility study have been somewhat disappointing and the economics appear somewhat unfavourable when compared with the other reactor systems put forward by the industrial concerns. It is probable nonetheless that when the Windscale experiment has reached a more advanced stage, the possibility of installing an AGR in a ship will be reopened but, for the present, work will concentrate on land-based electricity production.

Vickers Nuclear Engineering

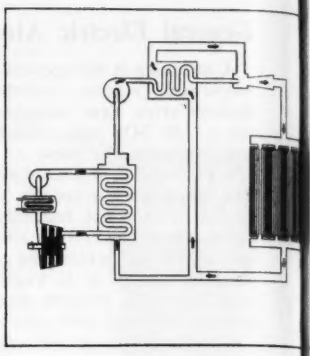
The design of the steam-cooled heavy water-moderated reactor proposed by V.N.E. is described in detail on pp. 246-249. Using U.S. prices, fuel costs of 0.25d-0.4d/kWh are estimated, associated with a "2nd off" construction cost of £2 million.



Reactor Assembly Plan View

STEAM COOLING

The Vickers Nuclear Engineering Ship Propulsion Proposal



Reactor Circuit Flow Sheet

CONCEIVED from the outset as a marine reactor, rather than as a modified land-based plant, the 150 MW(t) steam-cooled heavy water-moderated reactor designed by Vickers Nuclear Engineering, a consortium of companies comprising Rolls-Royce, Foster Wheeler and Vickers, holds both the promise of good steam conditions for the turbines and a minimum of moving parts within the primary containment shield. The system is peculiarly insensitive to accelerations that would be imposed upon it by movement of the ship, or the attitude of the plant, and the fluid control system permits shut-down independent of external supplies and irrespective of the position of the reactor (not forgetting the possibility of the ship turning turtle). The system can be readily scaled so that different power outputs can be obtained from the basic design without resort to reactor experiments, and basic alterations to either the reactor physics or the engineering structure. The large negative temperature coefficient at all power levels throughout the fuel life should permit the introduction of plutonium once metallurgical conditions have been satisfied.

Basic Circuit (see Flow Sheet above)

The reactor is moderated by heavy water, maintained at a temperature of about 70°C, the bulk of which is contained in an aluminium calandria pierced by aluminium tubes. These contain the fuel elements enclosed in stainless steel tubes thermally insulated from the calandria tubes by a blanket of helium. The fuel is uranium dioxide, enriched to 1.7% in U^{235}, canned in stainless steel, 19 rods making up a complete fuel assembly. The coolant is steam which enters the top of the reactor at a temperature of 260°C and is heated to 520°C, the mean steam pressure being 600 p.s.i.a. In a prototype model it is proposed that the primary circuit contains a secondary heat exchanger in which steam is raised to drive the turbine; this is regarded as an interim measure only, desirable in a prototype for safety reasons. Experience with the plant should lead to the elimination of this heat exchanger and the use of live steam in the turbine.

The returning condensate from the secondary boiler is evaporated in a steam raising unit fed from the reactor outlet steam line, approximately 75% of this steam being used for the purpose. A considerable saving has been made in the power needed to circulate the primary coolant by the introduction of a thermo-compressor (Fig.1). The condensate is raised to a pressure of about 2,000 p.s.i., is heated in the steam raising unit, and is injected at 1,800 p.s.i. through a nozzle into a chamber, the body of which is coupled to the steam raising unit outlet. A vigorous pumping action results and the steam mixture passes back to the reactor for re-heating. Comparative designs using mechanical circulation and the thermo-compressor system show a saving in pumping power of approximately 7½ MW, in addition to a reduction in maintenance problems with the thermo-compressor system.

Table I.—Power Plant Parameters

Performance	
Reactor output (nominal)	150 MW
at full engine power	160.5 MW
at half engine power	82.5 MW
Core life, at full power	74,563 MWd
at half power	76,656 MWd
Core	
Core dia. (nominal)	10 ft
Core height (nominal)	10 ft
No. of fuel channels	186
Lattice pitch (triangular)	8 in.
Calandria tank i.d.	10 ft 4 in.
inside height	10 ft 8 in.
Calandria tube	Aluminium alloy
dimensions	3¼ in. i.d. × ⅛ in.
Fuel channel barrier tube	Stainless steel
dimensions	3.1 in. i.d. × 0.015 in.
No. of moderator tubes	147
Moderator tube	Aluminium
	5.06 in. i.d. × 0.03 in.
Heat barrier gas	Helium
Reflector	
Radial, D_2O (nominal)	2 in.
H_2O	6 in.
Axial, D_2O (nominal)	4 in.
H_2O (combined with structure cooling)	nominal
Fuel	
Material	UO_2
Density	10 g/cc
U^{235} content	approx. 1.7%
No. of rods per element	19
UO_2 pellet dia.	0.50 in.
UO_2 pellet length	0.75 in.
Canning material	Stainless steel
Canning thickness	0.010 in.
Active fuel rod length	10 ft
Wt. of UO_2 per element	162 lb
Total wt. of UO_2	13.6 tonnes
Weight of fuel element assembly (including stand pipe plug)	200 lb
Element max. surface temp.	680°C
Element max. centre temp.	1,700°C
Moderator	
Material	Heavy water
Wt. in tank (control tubes full)	50,000 lb
Wt. in external circuit	5,000 lb
Heat production in moderator	10.5 MW
Moderator circulation rate	138 lb/sec
Moderator reactor inlet temp.	50°C
Moderator reactor outlet temp.	90°C
Reactor Cooling	
Coolant	Steam
Mean pressure	600 p.s.i.a.
Pressure drop in coolant channel	20 p.s.i.a.
Reactor total steam flow	1.74×10^6 lb/h
Reactor coolant inlet temp.	260°C
Reactor coolant outlet temp.	520°C
Max. channel steam velocity	180 ft/sec
Primary Steam Circuit	
Circulators	2 × thermocompressors (T.-c.)
T.-c. nozzle steam	1,800 p.s.i.a. 650°F
T.-c. nozzle steam flow	212,300 lb/h
T.-c. suction steam flow	657,820 lb/h
T.-c. suction steam	570 p.s.i.a. 496°F
T.-c. discharge steam	640 p.s.i.a. 500°F
Feed pumps (2) drives	Turbines
Aux. feed pumps (2) (capacity 7%)	Electric
Steam flow to secondary steam generators	2 × 212,300 lb/h
Minimum feed water pressure	525 p.s.i.a.
Live steam feed inlet temp.	340°F
feed outlet temp.	350°F
Secondary Steam Circuit	
Secondary steam pressure	420 p.s.i.a.
Secondary steam temp.	850°F
Secondary steam flow	2 × 212,400 lb/h
Physics for Hot Clean Core	
Enrichment	1.7%
k_∞ (moderator tubes full)	1.2212
k_∞ (moderator tubes empty)	1.1122
k_{eff} (moderator tubes full)	1.1345
k_{eff} (moderator tubes empty)	0.9214
Reactivity break-down :—	
Equilibrium xenon and samarium	4.2%
Excess of override to equilibrium xenon	3.3%
Allowance for fuel burnup	6.0%
Allowance for temperature coefficient	2.8%
Shutdown	5.0%
	21.3%
Total controlled by moderator tubes	21.3%
Initial conversion factor	0.53
Average conversion factor	0.52
Axial form factor	1.48
Radial form factor	1.17
Average thermal flux in fuel	2.12×10^{13}
Average thermal flux over core	4.19×10^{13}

The reactor tank is surrounded by an iron and water shield and carries overhead a massive platform containing two eccentric rotating plugs which allow access to individual fuel channels by the charge machine, permanently installed over the reactor and capable of storing three active fuel elements while at sea.

A novel feature of the reactor system is the method of control; 147 tubes are provided in the moderator tank coupled (in the main) in threes, connected to a battery of valves, separately controlled, which permit the level of the heavy water in these tubes to be adjusted to control reactivity and also to provide a high degree of flattening across the core.

The reactor in its shielding and the primary circuit is contained within a steel vessel, access ports being provided to allow maintenance of the heavy water valves should this prove necessary.

Reactor Tank (see page 248)

The calandria tank is of aluminium, alloyed with ½% magnesium with a wall thickness of 0.625 in. Inside diameter of the tank is 10 ft 4 in. and the inside height, 10 ft 8 in., the nominal size of the core being a cylinder 10 ft high and 10 ft in diameter. The tank is pierced by 186 pairs of concentric tubes, of which the outer, made from aluminium alloy (3% Mg), is welded at both ends to both ends to the core tank, whereas the inner stainless steel tube is welded to the standpipes, also made from stainless steel, the latter being joined to the core tank by a mechanical seal, see Fig. 3.

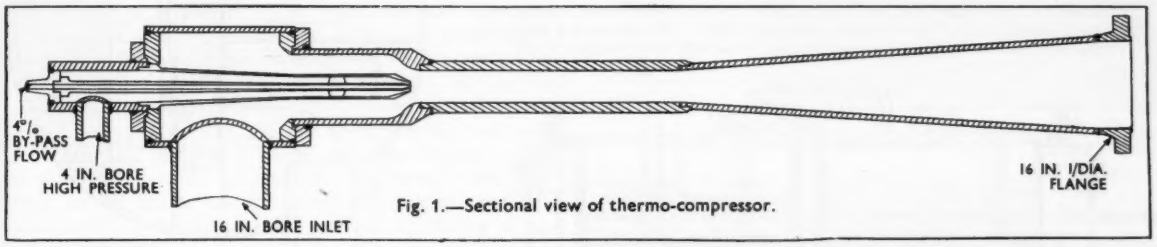


Fig. 1.—Sectional view of thermo-compressor.

Each of the aluminium tubes in the tank is 3.625 in. i.d. and has a wall thickness of 0.125 in., whilst the stainless steel tube is 3.1 in. i.d. with a 0.015 in. wall. This tube is unstressed since the interspace is filled with helium, which is maintained at the outlet steam pressure by a differential pressure valve; it is also monitored for leaks. The stainless steel barrier tubes, in which are suspended 19 rod fuel elements, are provided with bellows assemblies to cater for expansions and at the top end are fitted with detachable seal plugs for charge and discharge.

Steam enters the channels from a ring main at the top of the reactor through individual connections to the barrier tubes and is taken out at the bottom through adjustable gags to the outlet ring main. Three layers of pipes accommodate the connections to the 186 channels.

A cast aluminium alloy, light water-cooled hollow diagrid is attached to each end of the calandria tank by welding round the periphery and to each of the fuel channel stand pipes by means of double ring nuts which can be positioned to accommodate any lack of parallelism, and which serve to distribute the load. These two diagrids take the total thrust of the reactor under all conditions of acceleration.

Fuel

Uranium dioxide enriched to 1.7% is sintered into pellets 0.500 in. diameter and 0.750 in. long; these are clad in 0.010 in. thick austenitic steel (Jessops R20). The cladding is in the form of strip material, turned up along two edges so that a helical spacing fin is formed when the strip is wrapped round the fuel pellets and twisted axially before undergoing a continuous automatic edge-welding process (Fig. 2). Adjacent rods have opposite hand fins, so that good mixing of the steam coolant takes place through the channel. Individual rods are 12 ft long and 19 of these are assembled into a complete fuel element. They hang from the upper end of the barrier tubes at the top of each fuel channel, and are also attached to the seal plugs fitted in the stand pipes at the top face of the reactor. At the ends of the rods, porous alumina pellets are provided for absorbing fission product gases and to maintain a clear space between the heavy end pieces and the reactor core region.

Fig. 2.—A length of fuel rod with integral helical spacing fin.

Charge and Discharge

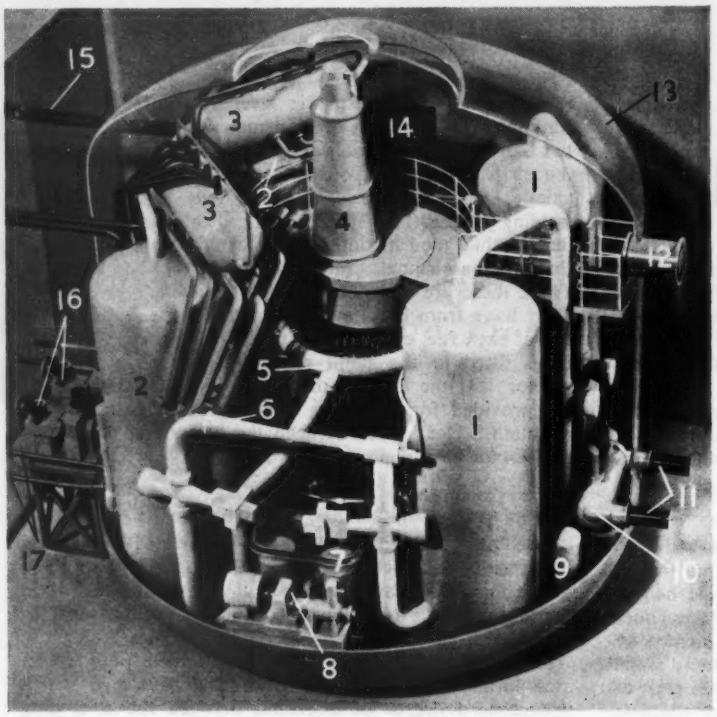
The charge machine comprises a shielded outer case with inside, a four-chamber rotatable magazine. Mounted above this is a chain rammer and hoist, while below in the shielding is an access tube which can be lowered to connect with the fuel channels of the reactor.

Each stand pipe is closed by a sealed plug which incorporates a deformable metal sealing sleeve which undergoes a degree of extrusion between the steel plug and the bore of the stand pipe when it is inserted, the surface metal being either silver or gold. A system of rollers and cams in the plug, allows the plug to be withdrawn or inserted with the charge machine chain under tension. Initial tests on this system have shown high integrity after many thermal cycles and many insertions and removals.

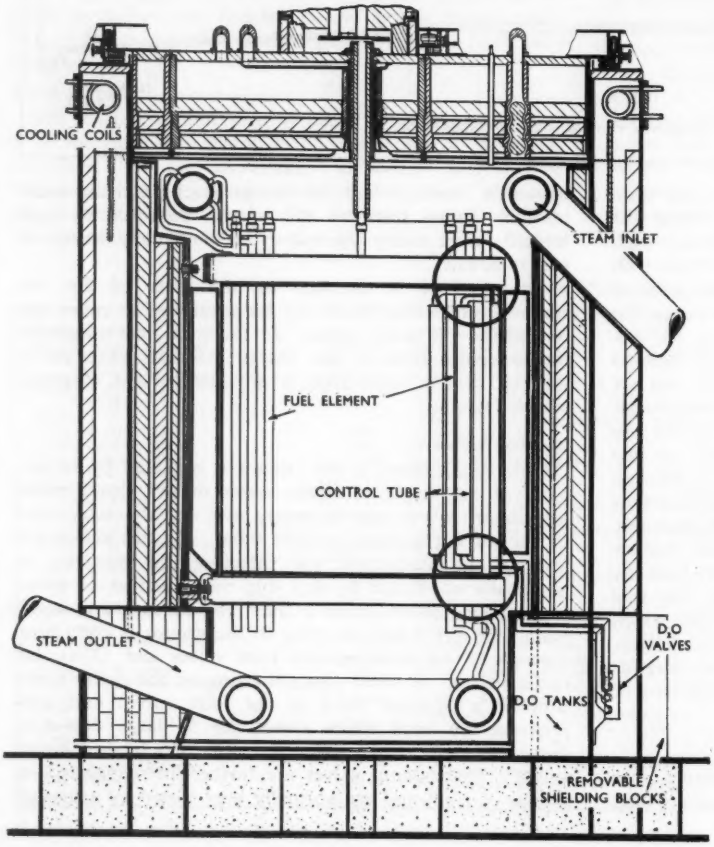
The machine is mounted on the inner of the two eccentric turntables which can be positioned to cover any one of the 186 stand pipes. To facilitate final alignment the nosepiece tube of the charge machine when partly lowered over a stand pipe is provided with a magnetic search facility.

Control Tubes

Criticality control of the reactor is obtained by adjustment of the height of heavy water in 147 closed-ended aluminium tubes; approximately 40% of the total core moderator is contained in these tubes. By this design the level of the moderator, and therefore the reactivity, is practically unaffected by any ship movement as no gross level change results from a tilt. The tubes are grouped mainly in threes and the level in the groups is controlled through 53 solenoid-operated inlet valves and 53 similar outlet valves. A small pump drawing on the dump tanks supplies a constant head to the inlet valves and also provides the head which closes the 53 large flow-area dump valves located between the pairs of inlet and outlet valves. These dump valves are further interconnected in groups of eight and are normally kept closed by a master



Figs. 4 (above) & 5 (below)—General arrangement of the reactor. Key : 1—Primary heat exchangers ; 2—Secondary heat exchangers ; 3—Secondary steam drums ; 4—Charge machine ; 5—Inlet steam main ; 6—Thermo-compressor ; 7—Heavy water coolers; 8—Auxiliary feed pump; 9—Ion exchangers; 10—Dump Condenser; 11—Sea water inlet and outlet pipes; 12—Containment access airlock; 13—Containment shell ; 14—Containment air cooler ; 15—Secondary steam to turbines; 16—Feed pump driving turbines; 17—Feed water supply pipes.



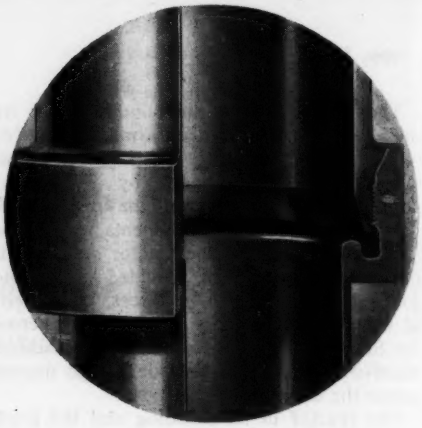
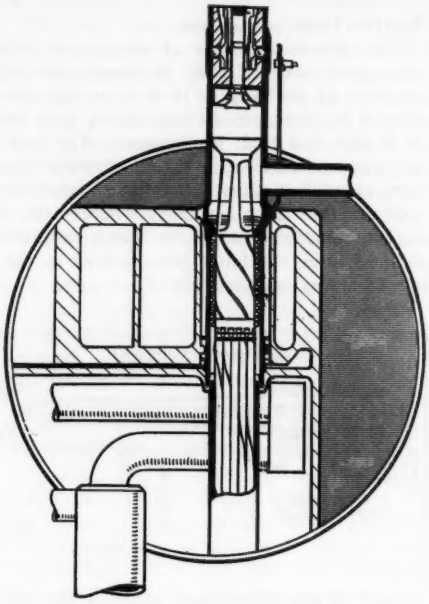
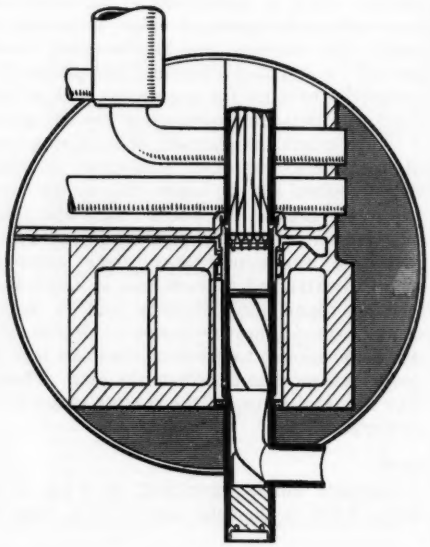


Fig. 3 (above)—Stainless steel to aluminium calandria joint. (The inner tube is not shown.)



Figs. 6 (above) & 7 (below)—Detail of fuel channel and control tube at inlet end and at outlet end, respectively.



solenoid valve designed with normal fail safe provisions. Dumping of the heavy water from the moderator tubes under scram conditions takes seven seconds.

The large amount of reactivity controlled by the moderator tubes allows, even with an enrichment of only 1.7%, complete xenon override (equivalent to a change of 2.3%) without the need for burnable poisons. In this context it is interesting to note that plutonium derived from natural-uranium graphite-moderated reactors, taken to a burn-up of 3,000 MWd/t contains almost exactly the optimum concentration of burnable poison in the form of plutonium-240.

The moderator temperature coefficient of the reactor is calculated to be -1.6×10^{-4}/°C and the fuel coefficient -3.1×10^{-5}/°C. As the moderator is maintained at a low temperature (70°C) and the mean fuel temperature is high (640°C) the second effect predominates; on coming up to power the net negative change in reactivity is 2.7%. A cool moderator also implies little change in spectrum with power which is of great importance when plutonium is considered as fuel.

Primary Coolant Circuit

Steam enters the reactor just above its saturation temperature at 500°F and is superheated to 970°F, the mean pressure being 600 p.s.i.a. and the total throughput 492 lb/sec at design power. Some 372 lb/sec is diverted through two steam generators where steam is raised from the feed water at a pressure of 1,800 p.s.i. and at a temperature of 650°F. This high pressure steam supplies the nozzle of two thermo-compressors which the reject steam from the generators enters at a pressure of 570 p.s.i.a. and a temperature of 496°F. In this way pumping power is derived from high pressure steam without going through a Rankine cycle. In each thermo-compressor are two concentric nozzles, the smaller being 4% of the total area. Only the outer nozzle steam supply passes through the nozzle control valve; the size of the smaller nozzle was determined as that which would pump the largest quantity of atmospheric steam (to deal with the reactor's shut-down heat under severe collision conditions) consistent with satisfactory performance under scram conditions at full circuit pressure.

Once-through, primary steam generators were chosen, because of their inherent low water hold-up, thus easing the containment problem. Two identical units are provided, each comprising an economizing evaporating and superheating tube bank in one shell. High pressure water enters the tubes at a rate of 212,410 lb/h at 348°F and 2,080 p.s.i.a. All banks are of 1¼ in. i.d., 9 s.w.g. tubing with ⅛ in. high fins, 0.064 in. thick, 6 fins/in. The primary coolant enters the shell at 970°F and 585 p.s.i.a. and leaves at a temperature of 496°F.

Twin secondary steam generators are envisaged in the prototype design each comprising evaporating and superheating banks in one shell; the shells are cylindrical with hemispherical tops and bottoms, and house the square ducting in which the tube banks are situated. The superheater and evaporator sections are designed to be made of finned tubing and the evaporator and economizer sections of plain tubing. The primary coolant enters at 970°F, 585 p.s.i.a. and leaves (as water) at 340°F, 560 p.s.i.a., the flow being 210,420 lb/h. Steam is fed to the turbine at 800°F, 420 p.s.i.a., the feed water being at 250°F, and throughput 212,410 lb/h.

Moderator System

The heavy water, which is blanketed with helium, is circulated by a variable speed canned motor pump. Baffles near the top and bottom of the control tubes even out the flow in the calandria and the static pressure of the circuit is maintained by a weir under a helium atmosphere, controlled to near atmospheric pressure. The main part of the moderator is circulated through four heat exchangers connected in series, three of which are feed heaters in the secondary steam circuit, where approximately two-thirds of the heat is lost. In the fourth the heat is rejected to sea water via a fresh water intermediate circuit. The pump is driven by an a.c. squirrel cage induction motor and is a variable speed so that the moderator inlet/outlet temperatures can be kept constant with varying reactor heat output. Circulation within the calandria is downwards, which promotes natural circulation of the moderator within the control tubes, no further cooling system being required. A recombination unit is included in the circuit and the output from this, together with the constant flow from the weir tank, passes through an ion exchange unit at a rate of 5 gal/min.

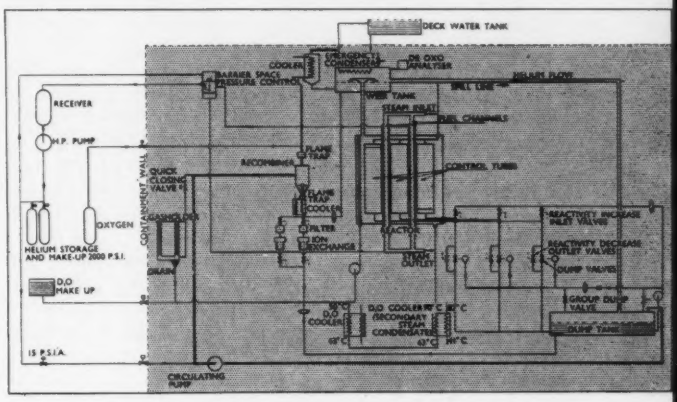


Fig. 8.—Flow sheet for the heavy water and helium circuits.

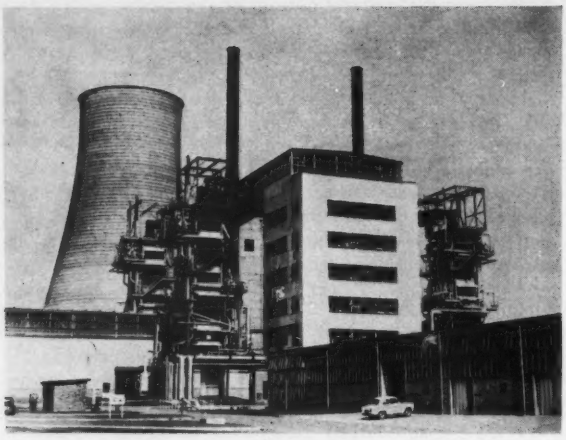
Shielding

The calandria is immediately surrounded by an annular aluminium tank of water of 10 in. radial thickness constituting the reflector which is surrounded by a shield of steel and water arranged in alternate layers to give a total thickness of 5 ft including the reflector.

The top shield is similar to the radial shield but the bottom presents a different problem as excess activation of the ship's bottom must be avoided and also radiation of the surrounding sea. It is concluded that a steel plate and girder construction filled with concrete provides the optimum design and initial calculation indicates that the probable thickness required is about 45 in. of ordinary concrete of specific gravity 2.4.

Containment is provided by a cylindrical upright shell 46 ft in diameter with a fat base plate and dished ends, the cylindrical proportion being of 1.5 in. thick steel and the weight approximately 187 tons excluding base. The maximum credible accident is taken to be the breakage of a 16 in. steam pipe in the primary circuit, followed by a reactivity decrease due to operation of the scram equipment of 0.67%/sec for 7.5 sec. It is calculated that 465 MWsec would be released within 120 sec, which would give a pressure increase of 125 p.s.i., neglecting heat losses which would probably account for about 10 p.s.i. A design pressure of 120 p.s.i.g. is therefore considered a reasonable figure.

Total weight of the plant and 480 ton containment vessel but excluding the drive aggregate is 2,100 tons.



Chapelcross

Britain's Second Full-scale Nuclear Power Station Opened near Annan, Dumfriesshire

IT would be easy to dismiss Chapelcross on the premise that the station is a straightforward copy of Calder—a full description of which appeared in the October, 1956, issue of *Nuclear Engineering*. In fact, however, there are a number of subtle differences between the two stations, many of them based on operating experience.

Furthermore, as Lord Plowden, chairman of the AEA, has pointed out, Chapelcross has the distinction of being Scotland's first nuclear power station as well as Britain's second, and the world's fourth. The station is, of course, intended primarily for plutonium production, simultaneously providing 140 MW to the electricity grid.

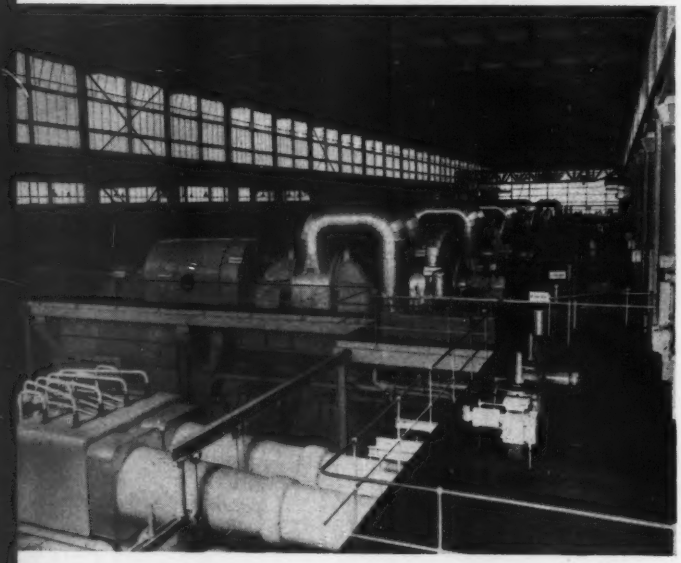
Work started at Chapelcross even before Calder was completed. The civil engineering contract was let to Mitchell Construction, of Peterborough, at the end of October, 1955. The first reactor went on load on February 25 this year, a few days ahead of the March 1 target date set when the project began. The station was officially opened on May 2 by the Lord Lieutenant of Dumfriesshire, Sir John Crabbe, O.B.E., T.D., M.C.

Chapelcross enhances a rather bleak stretch of the coast a few miles from Annan. A visitor who has also been to Calder is initially impressed by the more compact grouping of the four reactors. Calder was, of course, built in two groups of two reactors. The decision that Chapelcross should have four reactors from the start has enabled the designers to make much better use of the site.

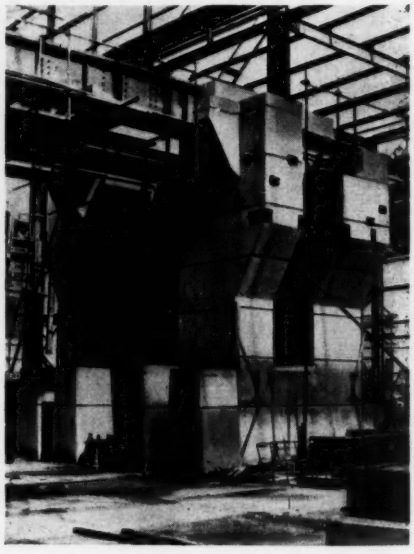
In this connection the Authority are to be commended for calling in as consulting engineers, Merz and McLellan, to handle the power plant layout, service, and to act as construction agents. With the agreement of the Authority Merz and McLellan retained a firm of architects, L. J. Couves and Partners, to plan ancillary buildings associated with the station.

As at Calder, the Authority placed orders for the equipment of the reactors, heat exchangers, blowers and turbo-alternators and carried out the inspection and progressing of the plant—except for the turbo-alternators which were left to the consulting engineers. All other contracts were placed by Merz and McLellan. Because of the extremely tight schedule for construction and the fact that work was proceeding on both Calder and Chapelcross simultaneously detailed programming and progressing was called for. The consultants therefore had a very large site organization with about 150 personnel, many of whom were concerned with quality control. Monthly progress meetings were held on site between the AEA and the consultants.

Mitchells, as the main civil contractors, also held regular



The turbine hall contains eight Parsons turbo-generators. Each is rated at 23 MW and comprises a single flow H.P. unit coupled to a double flow L.P. unit. Dump condensers absorb surplus steam capacity.



Constructional joints in this mass concrete plinth were deliberately made into an attractive feature.

site meetings so that contentious matters affecting the large number of different unions could be discussed and resolved. This policy was entirely successful in preventing major disputes which could seriously affect construction schedules.

An important feature about Chapelcross which should not be overlooked is the employment of a large force of predominantly local labour for maintenance and, in some cases, supervision of the station. Excellent facilities have been provided for maintenance work with fully equipped workshops capable of handling most repairs. An apprentice training scheme will also be instituted.

Civil Engineering

Turning now to the actual construction of the station, Mitchells were responsible for the four reactor buildings, cooling towers and the turbine hall. In addition the company completed preliminary site clearance, several miles of access roads, various drainage systems, circulating water culverts of reinforced concrete and the fuel element cooling pond. Under a separate contract the company erected a 132-kV sub-station for the South of Scotland Electricity Board.

The subsoil consists of boulder clay overlying round sandstone rock at depths starting at 25 ft. To ensure a sound foundation the biological shields of the reactors —concrete structures with 7 ft thick walls, 90 ft high and 40 ft i.d.—were built directly on the rock. (At Calder raft foundations were used.) A significant feature of No. 4 reactor at Chapelcross was excavation to bed rock at 70 ft.

The concrete used at Chapelcross had to meet the same stringent requirements as at Calder: crushing strength 3,000 p.s.i. at 28 days and a dry density of 153 p.s.i. at 7 days. At first it was thought that the aggregate would have to be transported from quarries some distance away. After an extensive survey Mitchells discovered rich gravel deposits at Hardgrave, only seven miles from the site.

As some indication of the magnitude of the civil engineering work it is noteworthy that in 3½ years Mitchells excavated and removed some 200,000 cu. yd of clay and rock. Over 170,000 cu. yd of concrete was placed in all structures, a weekly figure of 2,500 cu. yd being attained during the peak period.

Design Changes

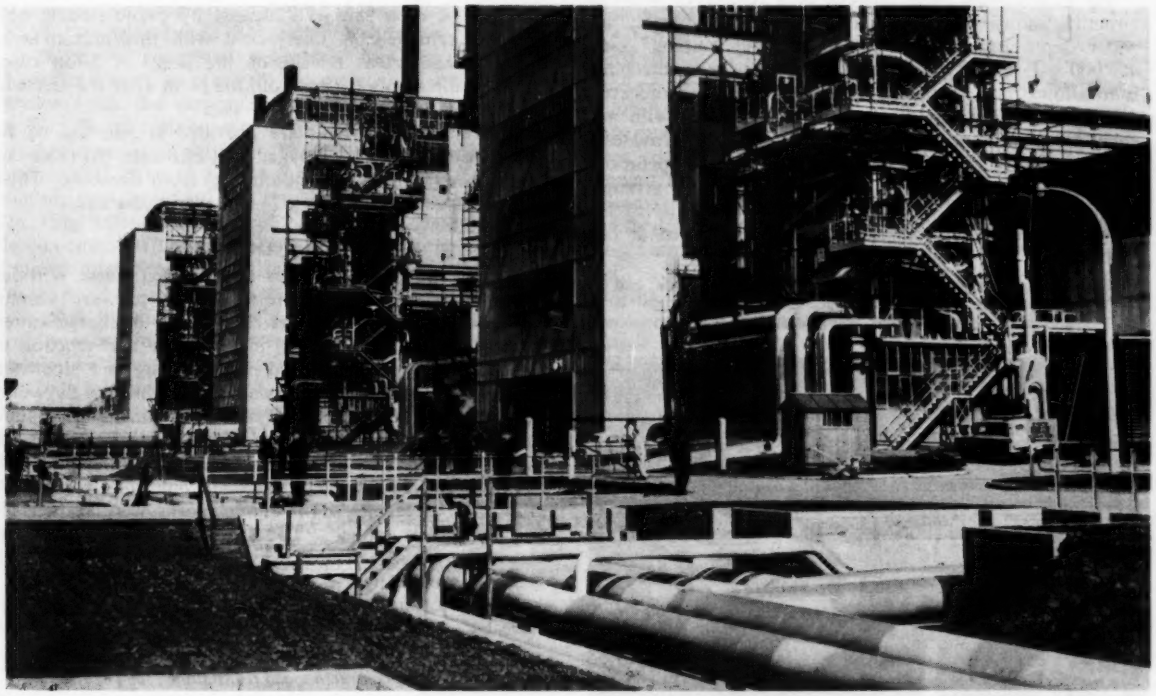
The most significant change in design in the reactor area is the inclusion of removable graphite sleeves in the fuel channels on reactors 2, 3 and 4. The decision to incorporate sleeving arises from the need to minimize the effect of Wigner growth by creating a thermal gradient and thus raising the temperature of the graphite so that the pile is inherently self-annealing.

This modification has not been extended to No. 1 reactor which was too far advanced when the decision was made. If necessary Magnox sleeves could be inserted into this reactor, although this will not be done unless absolutely necessary.

On the pressure vessel itself the principal changes concern the use of 3-in. plate where B.S.D. or thermocouple branches are joined to the vessel. Following research into problems of notch ductility more attention is being paid to accurate measurement of the pressure vessel temperature and there is now an additional number of thermocouples connected to the exterior surface; within the reactor, too, there is a greater emphasis on the measurement of temperature of both fuel elements and graphite.

So far as the CO_2 coolant circuit is concerned, any changes are mainly directed at reducing the effect of

Stewarts and Lloyds were the main contractors for supply, erection and welding of pipework systems including H.P. and L.P. steam piping in sizes from 15½-in. bore to 3-in. bore. Circulating water piping ranges from 28 in. to 4 in. in cast iron and mild steel. The company also supplied nearly 250 miles of E.R.W. tubes to Babcock and Wilcox for the 16 boilers.



Additional neutron flux measuring equipment has been installed in the No. 1 Chapelcross reactor compared to the Calder reactors.

Instrumentation in the reactor control room follows closely on the Calder pattern except that the number of temperature recording points has been increased.

leakage. It was interesting to see that a fabricated 54-in. valve has been included in the circuit of No. 4 reactor—presumably to see whether a fabricated body is less prone to leakage than a cast unit. Spindles of the 54-in. valves are now in stainless steel.

The precipitation chambers used for burst slug detection are now all fabricated. Initially these vessels were castings but in view of the difficulties experienced on the early Calder reactors a change in the method of manufacture was made.

Cooling Pond

At Calder spent fuel elements can be easily transferred from the reactor to the Windscale cooling pond so that it was not necessary to provide separate facilities on site. Chapelcross is some 70 miles from Windscale, however, and a pond has therefore been provided on the station.

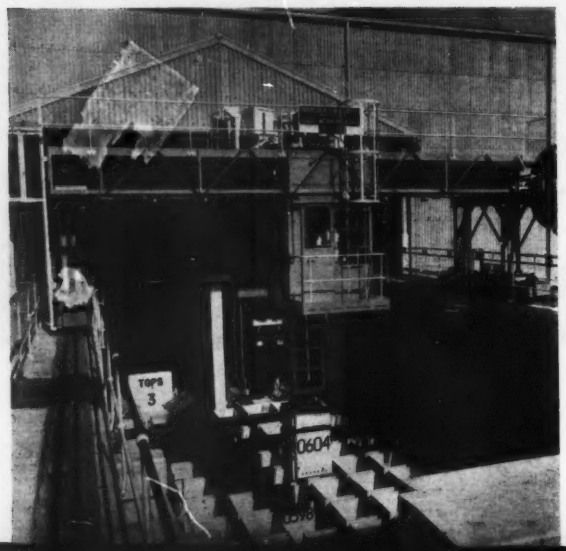
The Chapelcross pond consists of a reinforced concrete structure housing two rectangular storage ponds, the water depth being 18 ft and each pond holding about 400,000 gallons of water. The main purpose of the pond is to allow "hot" elements to cool by natural radioactive decay thus easing shielding problems associated with any subsequent handling operations. The pond also provides a storage point in the fuel cycle so that refuelling operations are completely independent of external transport arrangements.

Up to three reactor discharges can be handled at one time so that the elements can decay over a period of some months before being transported to Windscale by road in a specially designed vehicle with heavily shielded container.

After removal from the reactor, spent fuel cartridges loaded in 24-element flasks are carried to the pond in a heavy cast-iron container. At the pond, Babcock and Wilcox have installed seven specially designed cranes. The principal unit is a 50-ton electric overhead travelling crane which places the heavy cast-iron container in the pond. Each pond is serviced by a 1,600 lb travelling platform with a hydraulic ram and grab mechanism capable of removing the flask and spent elements from the container. Two 3½-ton skip-handling Goliath cranes, one to each pond, carry the filled baskets to the prearranged positions for storage. The skip-handling machine is a remote ram-operated grab mechanism arranged on a travelling gantry across each pond, with a variable gear for traversing. The position of each skip is indicated by photo-electric cells and the ram gear is interlocked with this indication to prevent inadvertent release of the skip. A 1-ton crane removes the empty basket from the pond after the elements have been transferred to the skip.

Separate arrangements are provided at one end of the pond for (a) storing damaged fuel elements, (b) removing thermocouple wires (by guillotining) from elements. These operations are serviced by a 7½-ton overhead crane.

Special purpose cranes were developed by Babcock and Wilcox for the twin cooling ponds, one of which is shown here before it was filled with water.



Principal Contractors

Apart from the contractors already mentioned, Whessoe were responsible for the four reactor pressure vessels; Strachan and Henshaw, fuel charge and discharge equipment; Babcock and Wilcox, manufacture and erection of the 16 boilers and associated main ducting and pipework. Thos. W. Ward, of Sheffield, were the mechanical dayworks contractors with particular responsibility for the installation of B.S.D. gear, charge pans, graphite base plates and core, thermal shield and the charge tube cooling equipment. Stewarts and Lloyds were the main pipework contractors whilst W. T. Henley's Telegraph Works were responsible for the electric cables. The CO_2 storage installation was handled by the Distillers Co., the burst slug detection gear being made by Plessey Nucleonics.

In the turbine hall, the eight 23MW turbo-generators were by C. A. Parsons. English Electric supplied the four 11-kV switchboard units.

Further sub-contractors and translations, see page 269.

FUEL ELEMENTS for DRESDEN (U.S.A.)

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The 180-MW Dresden station will have a reactor of the uranium dioxide boiling-water type. Each fuel rod is about 10 ft long, assembled from 27-in. segments. The latter consist of Zircaloy-2 tubing, filled with (sintered) pellets of the fuel and closed by plugs welded to the ends. In order to preserve the useful properties of Zircaloy-2 special fabrication techniques coupled with refined testing procedures have to be employed. In conclusion, probable future trends regarding the fabrication cost of these elements are discussed.

THE fuel segments for the Dresden Nuclear Power Station consist of uranium dioxide cylinders, or pellets, enclosed in Zircaloy-2 tubes and retained by end plugs. Fuel element assemblies consist of four segments each $\frac{1}{2}$ in. in diameter and 27 in. long; these are assembled into 6×6 square bundles 5 in. wide and 10 ft long (see Figs. 1 and 2). The end plugs used as closures serve as connectors to attach the segments one on top of the other to form the required 10 ft length. At the point of contact between two adjacent end connectors there are thin spacers to maintain the tube to tube distance, offset possible contact of the segments during reactor service, and avoid possible "burnout" or fretting corrosion. The distance between tubes is dictated by physics parameters such as water to fuel ratio, which in turn determines criticality. The distance between segments in the present design is such that the tubing straightness required is the best that can be obtained using standard fabrication techniques.

It takes 144 segments[1] assembled into four layers of 36 segments each, to make up a complete fuel bundle; 480 bundles form the complete core load for the Dresden Station. Each fuel bundle is surrounded with a square Zircaloy channel or shroud. The number of segment end closures that have to be fabricated is about 140,000 not counting the losses. To fill the segments, four million $\frac{1}{2}$ in. long pellets are required. The physics, heat transfer, physico-chemical and mechanical design criteria imposed stringent tolerances on both, end closure and pellet fabrication procedures. The processes developed have been such, that the highest possible product yield is attained with no loss in fuel segment quality as required for trouble-free reactor operation. In this report, the materials, process and quality control methods applied in the fabrication of fuel elements for the Dresden Station, are described together with an assessment of the costs involved and a prediction of cost trends.

MATERIALS

Although both seamless and weld-drawn tubing have been used for fuel element jacketing, the seamless type was selected on the basis of wider testing experience both in AEC and G.E. experimental programmes. The fabrication of seamless tubing has been described elsewhere[2]. End plugs are either machined from large-diameter bar stock or hot-forged from small diameter bar[3]. Forging is accomplished by induction or resistance-heating the bar stock in air at 1600-1700°F for 2-3 seconds and then forcing the heated length into an appropriate die. The as-forged end plugs are then machined, thus removing the oxide accumulated during heating. Only a few thousandths of an inch are removed after forging, hence this method results in substantial savings in machining and materials, as compared to machining from large-diameter bar stock. Because of the geometry involved, only 65% of the required end plugs are hot-forged.

All zirconium materials used originate from magnesium-reduced sponge (as obtained by the Kroll process) which is subsequently alloyed and cast into ingots under vacuum. Experiments carried out showed that tubing, produced from sodium-reduced sponge, is also acceptable for fuel element fabrication. Vacuum melting results in stringer-free mill products with superior corrosion resistance and mechanical integrity, as opposed to those obtained from inert atmosphere-melted ingots. A typical chemical analysis for Zircaloy-2 components is shown in Table 1.

Adherence to the chemical specifications is necessary for corrosion resistance in high temperature, high pressure water. Excessive amounts of aluminium, nitrogen and copper[4, 5] are detrimental to the corrosion resistance and hydrogen is an embrittlement-inducing impurity[4]. Other impurities such as hafnium (200 p.p.m.), cadmium (0.5 p.p.m.) and boron (0.5 p.p.m.) must be held to low levels for neutron economy. Of particular interest is the

Table I.—Typical Chemical Analysis for Zircaloy-2
(p.p.m. except as noted)

Cu	Sn	Ni	Al	Mn	Si	Cr	Fe	Mg	N_2	H_2	O_2
35	1.5%	0.058%	43	49	74	0.099%	0.13%	10	50	25	910

Remainder Zirconium

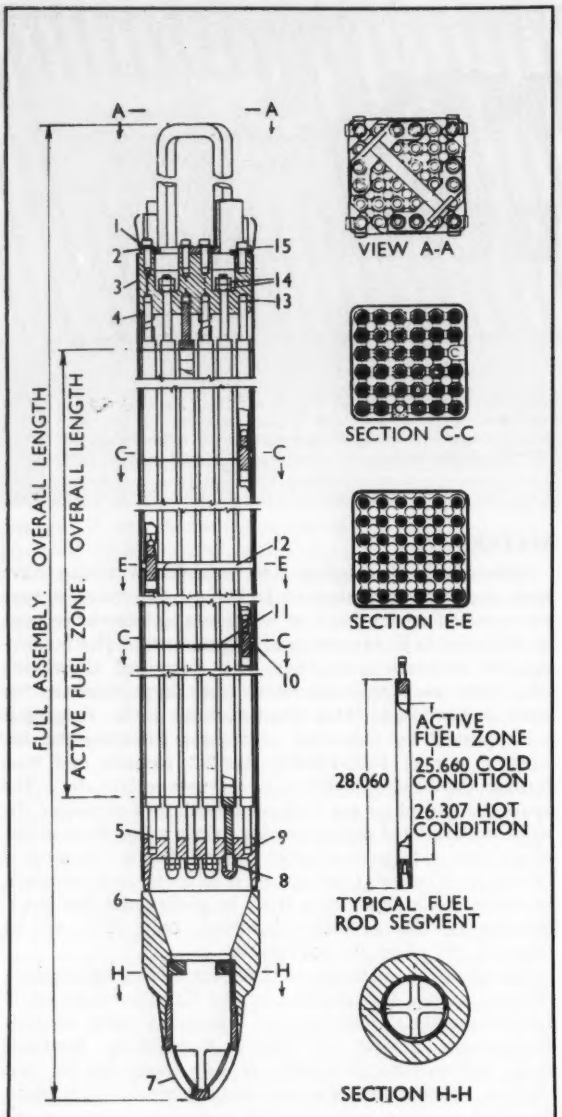


Fig. 1.—Fuel element bundle.

KEY

(1) Screw	(6) Bottom Transition Piece	(11) Spacer
(2) Lockwasher	(7) Orifice Nose Piece	(12) Space
(3) Channel	(8) Locknut	(13) Upper Tie Plate
(4) Spring	(9) Lower Tie Plate	(14) Nut
(5) Spring	(10) Lobe	(15) Lockwasher

Table 2—Typical Chemical Analysis of UO_2 Powder

(p.p.m.)	(p.p.m.)	(p.p.m.)
W .. 100	Mo .. 3	C .. 100
Fe .. 100	Cu .. 40	F .. 200
Ni .. 100	Ag .. 0.1	
Cr .. 50	Pb .. 2.0	
B .. 5	Sn .. 50	Remaining UO_2
Si .. 100	Ca .. 50	O/U=2.06 max.

fact that hydrogen concentrates at the cold side of the metal in temperature gradients, such as those existing through the fuel element cladding. Studies indicate that the initial hydrogen content should not exceed 40 p.p.m., to ensure a hydride-free fuel jacket. Because the tubing is subjected to numerous vacuum-annealing steps during fabrication, the allowable hydrogen limit is easily met.

To guarantee adequate corrosion resistance, representative coupons from incoming zirconium material are tested in autoclaves (stainless pressure vessels) operated with 1500-p.s.i., 750°F-steam for periods of 3 to 14 days. The maximum permissible weight gain for the longer period is 38 mg/dm^2; test procedures are based on statistical sampling. All tubing is hydrostatically tested at 3800 p.s.i., and representative samples are destructively tested for yield and tensile strengths. Reduction in area by cold working is limited to 25% to minimize end-closure weld cracking, and 15% cold working is required for strength in service. Dimensional requirements are 0.500/0.505 in. inside diameter, 0.033 in. wall thickness and straightness of 0.008 in. per ft. Small average size grains are desirable because of potentially higher ductility but no specific requirement in this respect is imposed for incoming material.

The uranium dioxide used for the pellets has been described elsewhere[6,7]. The UO_2 required for the Dresden Station must have an enrichment of 1.5% in U^{235}, therefore the starting material originates from the Oak Ridge separation plants as UF_6 gas. This gas is reduced to UO_2 by a series of processing steps through ammonium diuranate (ADU), the ADU being converted by pyrolysis to U_3O_8 and the latter to UO_2 by reduction in hydrogen[8]. A typical chemical analysis is shown in Table 2.

It is important that the O/U ratio is close to 2.00. Higher ratios result in the formation of U_4O_9, causing reduction in melting point temperature and lowering the effective thermal conductivity of UO_2 pellets. Both effects are undesirable, in that they impair the heat removal efficiency of the fuel elements. Melting is presently considered an operational limit because it causes fission gas release, which in turn may result in jacket ruptures from accumulated gas pressure at high exposures. The carbon content is limited to 100 p.p.m. since this impurity tends to lower the UO_2 stability in hot water.

FABRICATION

The UO_2 powder is mixed with a suitable organic binder, such as stearic acid, polyethylene glycol or paraffin, ball-milled and granulated to a free flowing constituency, then pressed at 20 p.s.i. to 6.3 ± 0.5 g/cm^3 green density. The binder is removed by pre-sintering at 450°C, followed by sintering in hydrogen atmosphere at 1550-1750°C[9]. The finished pellets are ground in order to obtain a uniform diameter and are then loaded into tubes. Important criteria for pellet quality are density (to be at least 95% of theoretical density), oxygen to uranium ratio[6] and structural integrity.

Successful end closures of the Zircaloy-2 tubes can be obtained only when the parts to be joined are clean, free of dust, dirt, grease or oxides. The tubing is washed in a detergent, then rinsed in hot water, dried and finally vapour-degreased. The tube openings are etched in acid solution (3.5% HF, 36% HNO_3 by weight), followed by rinsing and drying. End plugs are cleaned in a similar manner, but they are not etched since machining results in relatively clean surfaces. Cleaning is followed by these successive operations:—

(a) Pressing the first end plug into tube.

(b) Welding first end plug.

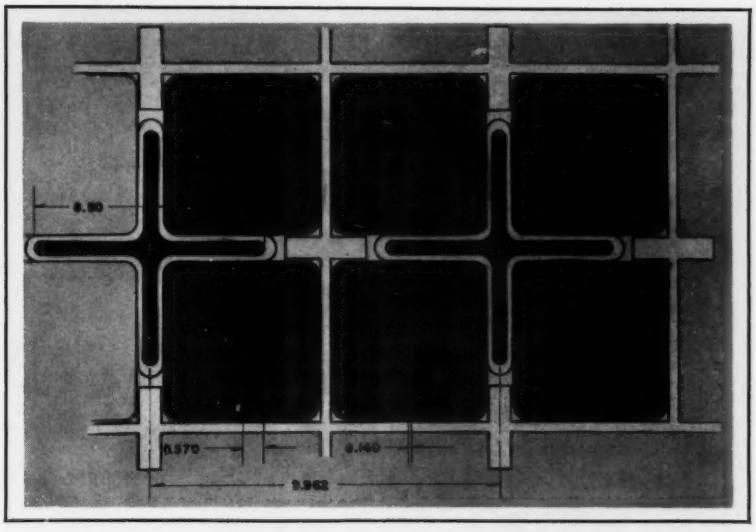


Fig. 2.—Fuel segment arrangement in reactor core, showing also the control elements. (36 Rod Assembly.)

(c) Loading segment with UO_2 pellets.

(d) Filling tubes with helium and assembling the second end plug.

(e) Welding of the second end plug.

(f) Testing and final assembly.

A tight fit is required at the weld junction to prevent blow-holes and peel-back. After loading with the pellets, the second end-plug junction must be freed of UO_2 dust, otherwise excessive undercutting and porosity will result at the weld zone.

The first end-plug weld is effected in an argon atmosphere, using a $\frac{1}{8}$ in. diameter, 2% thoriated tungsten electrode and 70 to 78 amp welding current. High frequency starting and a crater elimination step are also employed. The electrode remains stationary and the segment is rotated at about 14-15 in. per minute. The electrode tip is held at a distance of 0.03 to 0.04 in. from the weld joint, slightly offset towards the end plug. Straight polarity (the electrode being negative) is used. Copper chill blocks having the appropriate geometry were used to remove heat from the weld zone and thus reduce distortion resulting from intense localized heating. In addition, chill blocks help to reduce the slight amount of discoloration usually found along the heat affected zones.

The second end closure is welded in a helium atmosphere because of the desirability of having good heat transfer characteristics at the gap between UO_2 and fuel element jacket. In addition, helium provides an easy and reliable leak detection monitoring means, using a mass spectrometer. The parameters applicable to welding in helium are identical to those used for the first end-closure weld, except that the welding current is 48-52 amp and the speed of rotation is 24 in./min. To achieve a pure atmosphere inside, the welding chambers are first evacuated to a pressure of about 0.3 microns of mercury and then back-filled with helium or argon gas. The back-filling time is held to a minimum thus reducing contamination from microscopic leaks, when the system is isolated from the vacuum pump. The pressure in the chamber is kept constant at all times during welding, using an oil equalization valve. Batches of 100 to 150 segments can be processed before changing the chamber atmosphere. The entire operation of pumping-down and back-filling the chambers takes less than one hour for a system having a total volume of 90 ft[3]. A typical fuel segment is shown in Fig. 3.

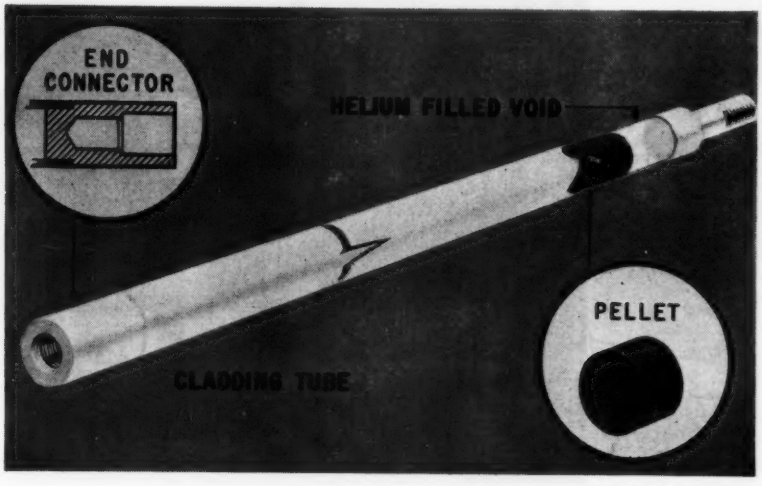


Fig. 3.—Fuel segment showing end plug configuration and UO_2 pellets.

The channel, or fuel bundle shroud is fabricated by seam-welding two " U " shaped, ten-foot long pieces, using appropriate jigs. No welding chamber is required, since the geometry of the parts is amenable to adequate inert atmosphere covering of the welding area.

INSPECTION AND TEST PROCEDURES

After welding the end caps, all segments are subjected to four major tests. These are:

Inspection for Dimensions

The physics of the Dresden Nuclear Power Station require that the tube-to-tube distance is 0.710 in. in the 6 × 6 fuel bundle arrangement. The closest proximity between two adjacent segments is 0.14 in. (see Fig. 2); as a result the 27 in. segments must have an overall bow of not more than 0.02 in., if segment contact is to be avoided during reactor operation. The axis of the tubing and end plugs must be such as to produce the required straightness. It is for this reason that the welding variables were carefully selected. Judicious choice of chill blocks eliminated practically all distortion at the end plugs where very close tolerances must be maintained. All segments are checked for straightness, and, if the specifications are not met, subjected to a straightening operation before final assembly.

Fig. 4.—Photomicrograph of a weld section.

Mass Spectrometer Testing for Leak Tightness

Leak tightness is measured by means of a helium mass spectrometer with a sensitivity capable of detecting leaks of the order of 10^{-8} cm^3/sec. This is accomplished by placing the segments individually or in groups in a chamber, evacuating with an auxiliary pumping system, and finally opening a valve to the mass spectrometer. Because of helium being present inside the segments, a slight jacket discontinuity is easily detected. Although only very few leaks have been detected so far, it is felt that this test provides an inexpensive insurance for fuel integrity.

Radiographic Tests of the Welds

These tests are complementary to the helium mass spectrometer test. Using a 250 kVA X-ray apparatus, an exposure of 45 mamp minutes, appropriate correction blocks and fine grain films, a sensitivity of 2% is achieved. This means that defects of 0.01 in. in diameter can be detected faintly. Penetrameters are used for each exposure, to determine film processing quality. Metallographic tests have shown that the selected standards, even allowing 0.01 in. defects, are satisfactory. Hydrostatic tests show that welds with undercutting defects not exceeding 0.015 in. in effective diameter fail above 95% of the pressure of those that are free from undercutting. The majority of the welds tested, however, do not fail at all. It is the tubing base metal which ruptures first. This is to be expected since the tensile and yield strengths of the weld, composed primarily of transformed beta-grains is higher than the base metal, which has an equiaxed alpha structure. An end-plug weld is shown in Fig. 4.

Testing for Surface Defects in Autoclave

The purpose of this test is to ascertain whether or not a given fuel segment has objectionable surface defects that will cause a rapid rate of corrosion of the cladding. To accomplish this, the segments are given a rigorous test at 750°F, 1400 p.s.i. pressure for a period of 72 hours. Acceptable segments are covered with a uniform black.

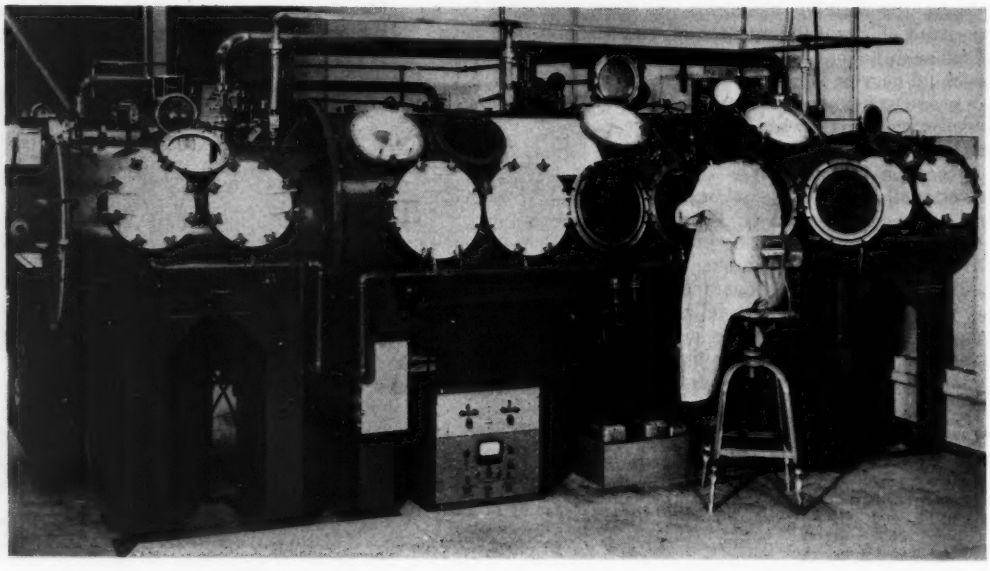


Fig. 5.—The production welding chamber.

lustrous, hard oxide coating, indicative of normal corrosion behaviour of Zircaloy-2. Any spots, streaks or "clouds" having grey, white or brown colour are suspect of objectionable surface contamination. In order to establish controls, segments with certain minor defects have been irradiated in VBWR to study the progress of the corrosion on these spots. The results will help in establishing realistic standards of acceptance for autoclaved segments. Meanwhile all defects are carefully scrutinized and marginal segments are reprocessed. Cleaning of the segments prior to the autoclave testing is very important and critical. Cleaning involves etching of the segments in HF-HNO_3 solution (3.5% HF, 36% HNO_3 by weight, remainder H_2O) followed by rinsing and drying. Segments failing to pass the autoclave test the first time, can be reprocessed by removing the oxide and recleaning. If they fail the second time, they must be scrapped, since any further reprocessing results in reducing the wall thickness to an undesirable degree. The number of welds that failed to pass the autoclave test thus far, is very small.

SPECIAL ASPECTS

Welds containing defects revealed from the radiographic inspection can be salvaged by multi-pass welding. Four or five passes are usually sufficient to reclaim the large majority of all rejected welds. Blow holes and undercutting are the most frequent defects encountered. Systematic studies revealed that both types of defect result from over-pressure of helium gas entrapped between end plug and tubing interface. Trapped helium has no room to escape during the weld cycle, except through the molten pool of metal, causing either a blow-hole or severe undercutting depending on the quantity of gas entrapped[10]. The end-plug design was adjusted to minimize this adverse condition; in addition, chill blocks (copper) were used to carry away the heat from the weld joint as rapidly as possible.

One of the most perplexing problems encountered was the preparation (cleaning) of the finished fuel segments for autoclave testing. Although extensive laboratory work was carried out during the developmental stages of the process, it was found that certain aspects of the cleaning procedure could not be scaled up without considerable modification. For example, certain acid strengths produced excellent surface cleaning, when using small-size coupons. When the identical acid concentrations were tried in large tanks for full-size segments, they proved unsatisfactory; the cleaning process had to be re-defined for large, production quantity batches. The magnitude of the problem for cleaning Zircaloy-2 segments has been adequately described elsewhere recently[11]. Although the methods discussed and tried by Kass and his associates may be helpful in small-coupon preparation, similar methods tried at APED did not produce satisfactory results. The problem, recognized early in production, was completely under control after several weeks, when it was found that surface retention of the zirconium salts after etching was a function of surface finish of the segments as received from the tube fabricator. If acceptable corrosion results were to be obtained from the autoclave tests, it was required that residual salts be removed thoroughly after etching. This is in general agreement with the results observed by S. Kass and associates[11].

IRRADIATION EFFECTS

Prototype fuel assemblies, containing UO_2-Zircaloy-2 clad segments with identical dimensions as those used in Dresden, have been irradiated in VBWR[1, 12]. Although the accumulated exposures are still modest, the heat rates

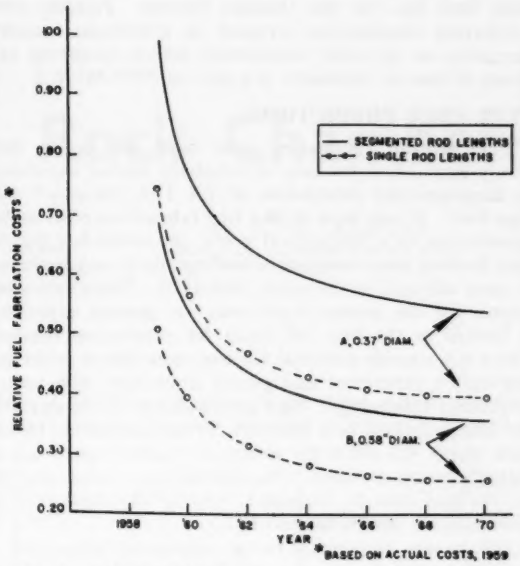


Fig. 6.—Projected fabrication costs for rod-type UO_2-containing zirconium alloy clad fuel elements.

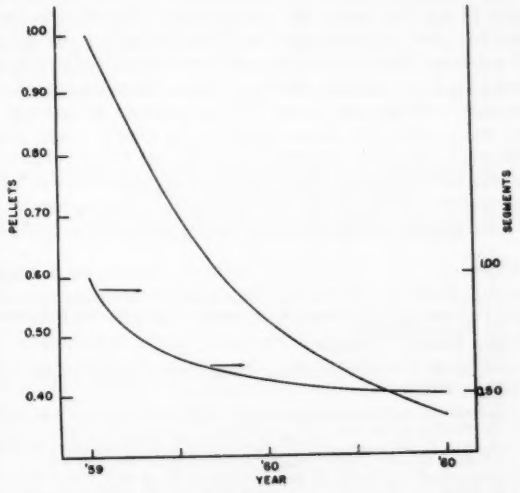
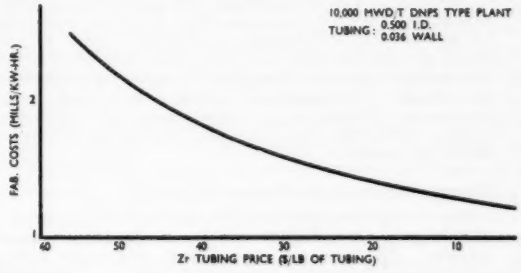


Fig. 7.—Projected UO_2 pellet fabrication costs, based on present-day experience (actual costs in 1959).

Fig. 8.—Influence of Zircaloy-2 tubing prices on overall fuel fabrication costs.



were 10% higher than those contemplated for the full-load, peak heat flux for the Dresden Station. Periodic post-irradiation examination revealed no distortion, excessive corrosion or any other measurable defects occurring as a result of reactor exposures in excess of 3000 MWd/t.

FUEL COST PREDICTIONS

Fuel element fabrication costs have not as yet been firmly established, because of relatively limited experience in large-quantity production of the UO_2-Zircaloy-2 clad type fuel. If one were to plot fuel fabrication costs taking present cost as a jumping-off point, one would find that the plot forms a very steep curve leading down, and beginning to level off only in the years 1966-1970. There is a good reason for the present high costs, i.e. present experience is limited to the first full loads for production reactors. There is a sizeable potential for cost reduction in prolonged fabrication experience and greater know-how with respect to present technology. Just as significant is the potential for cost reduction as a result of further irradiation experience which will allow the setting of realistic tolerances on manufacturing processes. In addition, cost reductions will be realized due to increased volume of production of materials, i.e. zirconium and UO_2.

Taking into account the factors mentioned above, certain indications can be given as to the expected trend in fuel fabrication costs. Fig. 6 shows several possible cases of fuel design configurations for a given reactor size and their projected fabrication costs through to 1970, taking present costs as the base point for comparison. The fundamental unit for cost estimates may be taken as dollars per pound of uranium fabricated. Savings may result from process simplification, design changes and standardization of product. At present, costs can be reduced by aiming at the most expensive items, these being labour costs, close tolerance materials, conversion (UF_6 to UO_2), yields of pellets and segments. Fig. 7 shows projected relative costs for pellets and segments and anticipated improvements.

Fuel element design plays an important part in final fuel costs, and therefore improvements in this area will affect cost reduction (see Fig. 6). Fuel element support, in assembly lengths of large reactor cores, appears to be a fundamental problem which can be evaluated only by experimental studies. Fretting corrosion is a largely unknown factor, but recent data[13] show that this may not be a problem in water-moderated reactors. Since the segmentation of a long rod length is more or less the result of sidestepping fretting corrosion, it is reasonable to expect relatively low-cost curves as shown in Fig. 6.

Power costs can be reduced by cheaper fuel fabrication as well as higher specific power and longer fuel life. The influence of Zircaloy prices on power generation costs in a specific case is shown in Fig. 8. Highly specific power limits and fuel life estimates cannot be given at present. Data available on high exposure irradiation behaviour of the oxide fuel element are restricted, and the limiting conditions for UO_2-Zircaloy jacketed elements have not yet been established. Current designs are based on the assumption that any amount of UO_2 melting is to be avoided if fuel element integrity is to be ensured. This assumption may not be true but its validity will be refuted only by the long and tortuous way of experimental verification. Operational limits of UO_2 fuel elements in reactor service will have a deciding effect on over-all power costs; experiments to determine these limits are now under way in the VBWR, and long exposures of 10,000 MWd/t or over will be achieved by the end of 1960.

In future power reactor core loads, standardization of fuel elements will contribute substantially toward reducing costs. At this stage of the art, however, no one can predict the most efficient type of fuel element, although the UO_2-Zircaloy-2 or UO_2-Stainless (rod geometry) are the most promising candidates for water moderated reactors. The problems relative to fuel cycle efficiency are continuously under investigation, and it is believed that standardization, such as is already established for test reactor fuel (Al-clad, Al-U alloy), can be achieved in operations on an industrial scale as well.

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Elements de Combustible pour Dresden (Etats-Unis).

La centrale d'énergie nucléaire de Dresden aura un rendement de 180 MW et utilisera un réacteur du type d'eau bouillante. Le combustible, l'uranium dioxide, sera sous forme de boulettes cylindriques calcinées, contenues dans des tubes à Zircaloy-2, la longueur totale de l'elément combustible étant de 10 pieds et formée de segments reliés entre eux par des tampons d'extrémité convenablement formés. Les détails des techniques de fabrication, en particulier le soudage, sont donnés. Des essais rigoureux comprennent l'inspection des dimensions, des conditions de surface, l'étanchéité aux fuites des éléments en général et la qualité du soudage.

Brennstoff-Elemente für Dresden (V.St.A.).

Das Atomkraftwerk in Dresden mit einer Leistung von 180 MW wird mit einem Reaktor vom Typ des Siedewasser-Reaktors arbeiten. Der Brennstoff, Urandioxyd, wird in der Form von gesintertem zylindrischen Schrot in Rohren aus " Zircalloy-2 " verwendet werden. Die gesamte Länge eines Brennstoff-Elements wird 3 m betragen, und es wird aus Teilstücken zusammengesetzt sein, die untereinander durch entsprechend geformte Endstopfen verbunden sind. Es werden Einzelheiten über die Fabrikationstechnik gebracht, insbesondere über die Art des Schweissens. Streng einzuhaltende Regeln beziehen sich auf die Nachprüfung der Abmessungen, die Oberflächengüte, die absolute Dichtigkeit der Elemente gegen Lecken und die Beschaffenheit der Schweissnähte.

Elementos de Combustible Para Dresden (E.E. U.U.).

La central de fuerza nuclear de Dresden, con un rendimiento de 180 MW, empleará un reactor del tipo de agua hirviente. El combustible, dióxido de uranio, será en la forma de pelotillas cilíndricas calcinadas, contenidas de tubos de Zircaloy-2, siendo el largo total del elemento 10 pies (3m048) hecho de segmentos interconectados por tapones extremos convenientemente formados. Se ofrecen detalles de las técnicas de fabricación, particularmente la soldadura. Pruebas rigurosas cubren la inspección de dimensiones, condiciones de superficie, estanqueidad a la fuga de los elementos en general y calidad de las soldaduras.

Thermal Storage in Rock Chambers

As more base load generation is provided by nuclear stations, so interest increases in energy storage. Theoretical studies made in Sweden—where a tradition of building in rock exists—show that hot water storage in rock chambers can be a promising approach.

By P. H. MARGEN
(*Head of Eng. Dept., Swedish Atomic Energy Co.; Director, Industrial Reactor Div.*)

ALTHOUGH many different storage devices have recently been examined in Britain, only pumped storage was thought to offer promise within the near future[1, 2]. An examination has recently been carried out in Sweden on a system in which energy is stored in the form of hot water under pressure—rather like the Routh's accumulators which were popular on the Continent in the 1930s. The method of pressure containment, however, is not conventional but comprises a chamber excavated in rock, which greatly reduces costs.

Basic Principles

The simplest method of high-grade energy storage by hot water is the Routh's accumulator illustrated in Fig. 1(a). This consists of a pressure vessel, filled with water at a temperature, t_a. Above the water there is sufficient space to allow good separation of the water and steam when steam is produced by reducing the pressure in the vessel.

During the peak load period, the pressure in the vessel is reduced gradually corresponding to a reduction in saturation temperature from t_a to t_b°C. The heat liberated in this way causes evaporation and the steam formed is passed to a turbine. The condensate is pre-heated by bled steam and is returned to the accumulator. The turbine is forced to operate at a varying steam pressure, starting at 478 p.s.i.a. if t_a=240°C and finishing at 183 p.s.i.a. if t_b=190°C, and must be designed to give a reasonably high average efficiency under these conditions, e.g. by fitting by-pass connections and nozzle control. During the off-peak period, water is pumped from the bottom of the storage vessel through the heat source to the top, until the entire vessel is again filled with water at temperature t_a.

The ideal cycle efficiency for an infinite number of feed heating stages is given by

$$E_i=(T_i-T_r)/T_i \qquad . \; . \; . \; (1)$$

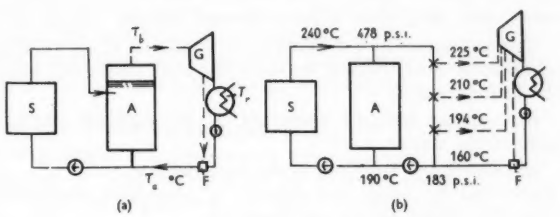

Fig. 1(a).—Simple system of hot water storage showing a Routh's accumulator feeding varying pressure steam to the turbo-generator.

Fig. 1(b).—By introducing into the steam line a series of throttling valves, pressure variations can be avoided.

where T_i is the mean level of the curve AB on the temperature-entropy diagram, Fig. 2(a), expressed in °K and T_r

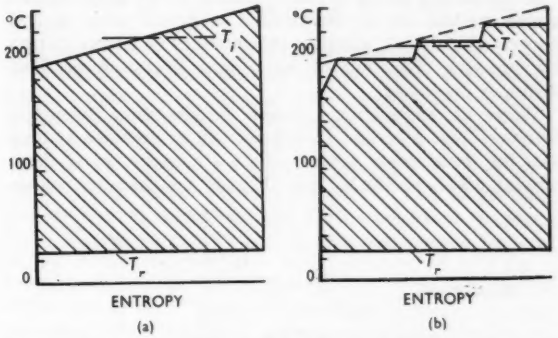

Fig. 2(a).—The temperature-entropy diagram appropriate to the simple storage system of Fig. 1(a).

Fig. 2(b).—Temperature-entropy diagram appropriate to a system as in Fig. 1(b) provided with three throttling stages.

is the temperature of heat rejection in °K. A characteristic value is 0.385 when t_a=513°K, t_b=463°K and T_r=300°K. An appropriate efficiency ratio for a large turbo-generator would be about 0.77 (allowing for operation at varying pressure), and the power consumption of the pumps would be about 2% of the generator output. The overall thermal efficiency from the heat source to the gross electrical output would thus be:

$$0.385\times0.77=0.296$$

giving a net efficiency of 0.290.

Constant-pressure Plants

The disadvantage of steam pressure variations can be avoided if the circuit is replaced by the one shown in Fig. 1(b), where water is taken from the top of the accumulator during the peak-load period, is passed through several throttling valves in series at each of which some steam is formed and this steam is passed to the appropriate turbine stage. The condensate, pre-heated by bled steam, is mixed with the water coming from the last throttling valve, and the mixture is pumped into the bottom of the accumulator at the temperature t_b. During the entire generation period the steam pressures remain constant, and the level in the accumulator separating the water at temperature t_a from the colder water at temperature t_b rises, until the vessel is filled with the colder water. During the off-load period, water is pumped from the bottom of the accumulator through the heat source and is

returned to the top of the accumulator at the temperature t_b.

The ideal efficiency of this cycle may be obtained from equation (1), T_t, however, being the mean level of the curve as shown in Fig. 2 (b) in a case where three throttling valves are used. The ideal efficiency obtained is 0.374, i.e., somewhat lower than for the Routh's accumulator as a result of the energy loss in the throttling valves. The turbo-generator efficiency ratio would be somewhat higher than before in view of the constant pressure operation, but the pumping power consumption would be greater since the entire water stored would have to be pumped back into the accumulator against the large throttling pressure drop as well as pressure drops in other components. The net result would be an overall thermal efficiency of about

$$0.374 \times 0.80 \times 0.925 = 0.277,$$

i.e. only about 95% of the value obtained with the Routh's accumulator. The advantages of a constant-pressure system are thus obtained at the cost of some reduction in efficiency.

If the energy losses in the throttling valves given by the above method are to be avoided, a device such as that illustrated in Fig. 3, allowing the recovery of energy during the pressure reduction of water and liberation of flash steam, is necessary.

Water at temperature t_a enters the chambers through a common inlet pipe and falls gradually in pressure as they pass the three steam domes, which are connected to three tapping points on the turbine. Finally the chamber rotates

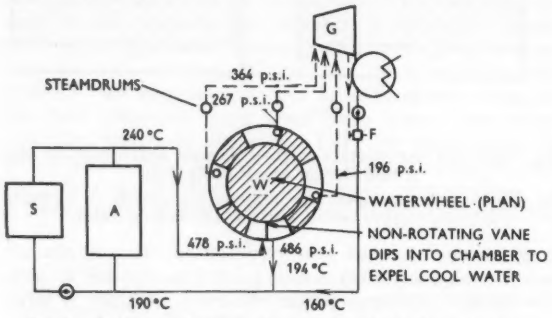

Fig. 3.—Schematic diagram of a system to feed steam at constant pressure from an accumulator, without throttling losses.

past the outlet pipe, where the water is discharged at the original pressure and at a temperature t_b. Small steam drums are provided as buffers in the pipelines to the turbine.

The ideal cycle efficiency and pumping power are identical to the values obtained with the Routh's accumulator whilst the overall efficiency ratio of the steam turbine and the water wheel should be about 0.80, i.e., comparable to the design with throttling valves, in view of the constant-pressure operation of the turbine. The overall thermal efficiency may, therefore, be expected to be about

$$0.386 \times 0.80 \times 0.98 = 0.302,$$

or say about 0.30.

It should be emphasized that the device illustrated in Fig. 3 is an example only of a variety of methods which can be used for recovering throttling losses. Furthermore such a device is a refinement and is not an essential component of thermal storage stations, nor does its omission seriously affect the overall economics.

The Heat Source

The quality of the rock in which the chambers for the accumulators are excavated and the available depth of

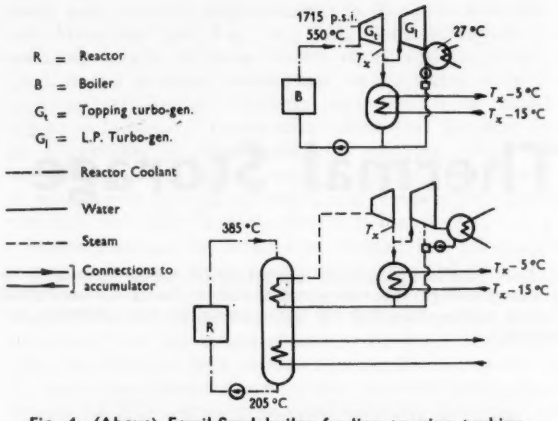

Fig. 4. (Above) Fossil fired boiler feeding topping turbine, condenser providing storage heat source. (Below) Similar system applied to gas-cooled reactors, the low temperature section of the heat exchangers providing a second source of thermal supply.

rock cover limit the permissible water pressure to values between 280 and 1,100 p.s.i., corresponding to values of t_a between about 220° and 290°C. A heat source suitable for such temperatures is, therefore, necessary. Temperature-entropy diagrams of three nuclear systems are illustrated in Fig. 5. The system is, of course, applicable to coal-, oil- or gas-fired water heaters designed for the same working pressure as the accumulator. The main merit is a low capital cost per thermal kW, even when built in very small units but the overall thermal efficiency is fairly low, e.g., $0.87 \times 0.30 \times 0.99 = 0.26$, when the boiler has an efficiency of 87% and 1% heat losses.

Reactor Main Heat Exchangers. This group includes most pressurized H_2O and D_2O-cooled reactors and boiling reactors currently proposed. For a given heat exchanger surface, a constant-pressure storage plant fitted with such reactors usually has about the same overall thermal efficiency (±1%) as a similar reactor without storage, assuming that the storage plant is fitted with a device for the recovery of the throttling loss.

Condenser of a High Pressure "Topping" Turbine designed for high steam conditions. The topping turbine (G_t in Fig. 4) would operate throughout the day, discharging its steam to the condenser and heating the storage water during off-load periods, whilst discharging steam directly to the low-pressure turbine, G_l, associated with the storage scheme during the remainder of the day. During the daily period of peak load, the steam drawn from the hot water accumulators, would be led to the additional low-pressure turbine associated with the storage plant. Varying pressure accumulators are quite suitable for this type of plant. The thermal efficiency is slightly lower than for a plant without thermal storage because of:

(i) the temperature difference of about 10°C necessary to promote heat transfer between the H.P. condenser and the heating water;

(ii) varying pressure operation of the turbines during part of the day;

(iii) about 1% heat loss in the accumulator.

These factors reduce the amount of electricity produced from the stored energy by about 7%.

Low Temperature Heat Exchanger in a nuclear plant fitted with two or more heat exchangers in series. This applies particularly to reactors having a relatively large coolant temperature range, such as gas-cooled, organic

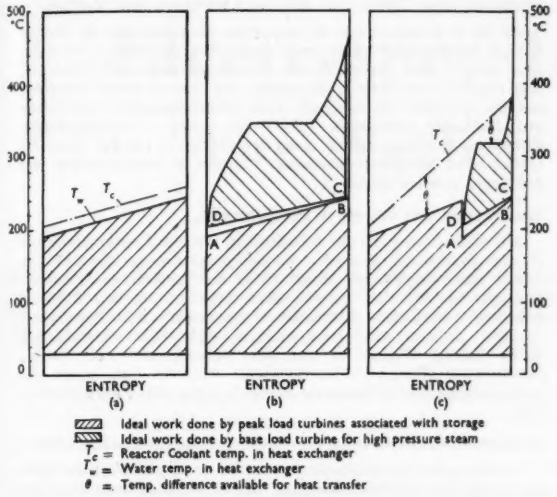

Fig. 5.—Temperature-entropy diagrams appropriate to three storage schemes. (a) Heavy water moderated and cooled reactor delivering from the heat exchanger water at 240°C, with a return of 190°C. (b) Fossil-fired system as shown in Fig. 4. (c) Gas-cooled reactor system, also as shown in Fig. 4.

liquid-cooled or certain proposed liquid-metal-cooled reactors. In Fig. 4 a plant suitable for a Calder Hall-type reactor is illustrated. It is assumed that the low-temperature heat exchanger supplies a thermal storage plant directly, whilst the high-temperature heat exchanger provides steam for a continuously operating topping-turbine, the condenser of which acts as the heat source for a second storage plant. To avoid having two storage plants of different design, varying pressure-type accumulators are assumed for both cases, although a constant-pressure-type accumulator would give slightly better results for the low-temperature heat exchanger. Pressure equalization between the different accumulators is ensured by interconnecting pipes.

The temperature-entropy diagram (Fig. 5c) shows that this type of combined cycle is very suitable for a gas-cooled reactor, achieving about the same ideal cycle efficiency as with dual pressure cycles now in common use. Small output reductions, however, result from the wetter steam in the low-pressure turbines, the varying pressure for some of the turbines and the heat loss in the accumulator. For typical storage cycles, e.g., that illustrated in Fig. 6, these losses reduce the output from the stored energy by about 6%.

The above indicates that the thermal storage plant could be used in conjunction with any desired type of fossil fuel or nuclear fuel plant, with an electrical energy storage ranging from 100% to about 93% of that obtainable without storage, or say 97% to 90% allowing for load variations met in practical operation. From this aspect thermal storage is thus superior to pumped storage, where only about 67% of the energy is recovered.

The Hot Water Accumulator

Experience exists in several European countries on the storage of large volumes of oil or gases under pressure in chambers excavated in rock. These chambers are generally made sufficiently leak-tight by cement injection or lining with steel plate. The maximum allowable design pressure is generally determined by the depth of rock cover available—being for example 30 to 40 atmospheres for about 100 m rock cover. Where the available depth of rock is great, an upper limit is generally set by the structural properties of the rock.

When such rock chambers have to be used for the storage of hot water, problems arise due to temperature changes of the water and the resulting expansion of any steel lining. One of the possible solutions is to construct a lining somewhat smaller than the excavation, and to fill the space between the lining and the rock walls with cool water. Pressure equalization takes place through special openings between the spaces inside and outside the lining, with the result that the lining may be designed to withstand only very small pressure differences, i.e., mainly those arising from differences in the densities of the water of the two sides of the lining. Thus the weight of steel is minimized. With this particular design the lining should be insulated—e.g., by multiple layers of stagnant water.

To avoid undue leakage of the pressurizing water to the outside, the walls of the rock are injected with cement, or if the rock is of poor quality, a second steel lining in contact with the rock may be used. Any leakage through cement injected rock is made up by pumps from the outside.

Estimates were made in Sweden regarding typical costs of constructing accumulators of this type with cement injected walls and all the required accessories for insulation and cooling. The result was an estimated cost of about 250 kr/m³ of hot water content, i.e., £17/m³. With a 50°C temperature range and a thermal efficiency of 29 to 30% the electrical storage capacity would be 15 to 16 kWh/m³, and the capital investment per kWh would thus be about £1.1. Expressed per kW extra electrical output the cost of the storage accumulator would amount to £5.5 for a five-hour daily peak load. To obtain the total cost per kW of the storage plant, the cost of the turbo-generator, pumps, throttling valves, etc., and associated building would have to be added, leading to a figure of about £5.5+28.5 or,

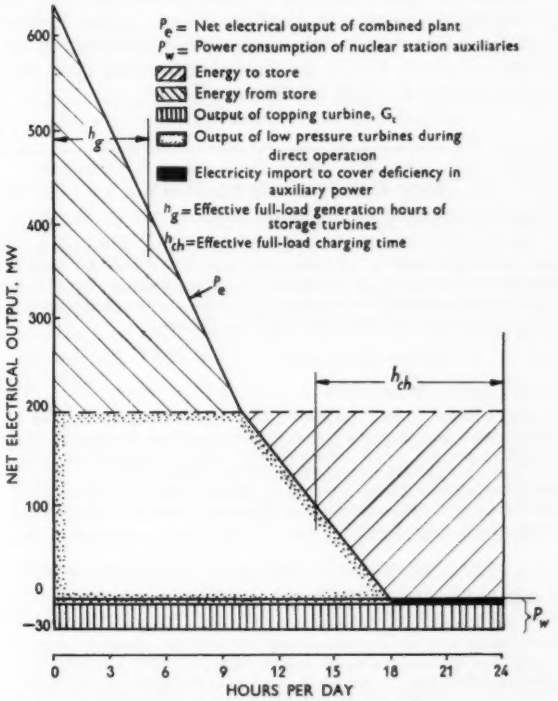
P_e = Net electrical output of combined plant
P_w = Power consumption of nuclear station auxiliaries
Energy to store
Energy from store
Output of topping turbine, G_t
Output of low pressure turbines during direct operation
Electricity import to cover deficiency in auxiliary power
h_g = Effective full-load generation hours of storage turbines
h_{ch} = Effective full-load charging time
NET ELECTRICAL OUTPUT, MW
600
500
400
300
200
100
0
−30
0 3 6 9 12 15 18 21 24
HOURS PER DAY

Fig. 6.—Typical daily load curve for a gas-cooled reactor supplying a thermal storage plant as in Fig. 4.

about £34 per kW for a large plant. This appears to be a typical value irrespective of the nature of the heat source, whether it be conventional or nuclear.

Economics

The economics of energy storage plants depend on local system conditions, e.g., the shape of the load curves, the composition of plant and the cost of fuel for different types of plant. For British conditions Duckworth and Jones[1] at Geneva stated that costs of several pumped storage schemes investigated were all in the neighbourhood of £50/kW excluding transmission. This is some 40% higher than the cost of thermal storage plant. The electrical energy requirement for pumping was estimated to be about 50% greater than that recovered during regeneration at peak load periods, whereas the corresponding figure for thermal storage plant would be an excess of about 10%. Thus the electrical energy requirement for pumped storage is about $(50\%-10\%)/1.1=36\%$ greater than for the thermal storage plant.

These figures lead to the following conclusions, assuming that a nuclear reactor of given output is available for a given number of hours per day for off-peak energy storage, and regeneration takes place for a given number of hours per day:

(a) If thermal storage is used, about 36% more energy and 36% more peak-load kW can be regenerated at peak times than with the use of pumped storage.

(b) The total fuel cost for both will be the same; the capital cost should be slightly less for the thermal storage plant but the capital charges might be slightly higher, as a somewhat shorter life might be appropriate for thermal storage plants than for pumped storage.

In very rough terms one can say that on an appropriate site the thermal storage plant promises to make available 30-40% extra energy and extra kW free of costs compared with pumped storage.

Whilst the above analysis is approximate and may be influenced appreciably by local conditions, it does suggest that thermal storage is well worth serious investigation for countries relying mainly on thermal generating plant and to an increasing extent on nuclear stations.

Emmagasinage Thermique dans les Chambres sous Roches.

Au fur et à mesure que la proportion de génération de charge basique couverte par les centrales nucléaires augmente, l'attention sera dirigée sur les méthodes d'emmagasinage de l'énergie. Des études faites dans le Royaume Uni dans le passé montrent que les systèmes de pompage sont économiquement supérieurs aux méthodes chimiques. Dans cet article, l'emmagasinage thermique de l'eau chaude dans des chambres taillées dans les roches là où des sites convenables existent, a manifestement des avantages considérables.

Speicherung von Wärme in Felskammern.

Mit dem Anwachsen der Mindestlast, die von Kernkraftwerken erzeugt werden soll, gewinnen Methoden der Energie-Speicherung immer mehr Beachtung. Studien, die in Grossbritannien bereits gemacht worden sind, zeigen, dass Systeme, die mit Pumpen arbeiten, chemischen Methoden wirtschaftlich überlegen sind. In dem Aufsatz wird nachgewiesen, dass Wärmespeicherung durch heisses Wasser in aus dem gewachsenen Fels heraus gearbeiteten Kammern beträchtliche Vorteile hat, wenn die entsprechenden Möglichkeiten durch die Lage des Werks gegeben sind.

Almacenamiento Térmico en Cámaras Labradas en Roca Viva.

Conforme la proporción de generación de carga básica cubierta por centrales nucleares aumenta, así la atención será desviada a métodos de almacenamiento de energía. Estudios hechos en el Reino Unido en el pasado demuestran que los sistemas bombeados son económicamente superiores a los métodos químicos. En este artículo se demuestra que el almacenamiento térmico de agua caliente en cámaras labradas en la roca viva poseen considerables ventajas en zonas donde hay sitios adecuados disponibles.

Acknowledgments

The author wishes to thank his colleagues H. Carruthers and S. Magdalinski who have suggested certain of the mechanical design features of the pressure vessels for location in rock and Professor Reinins of Vattenbyggnadsbyrån, who has carried out the cost estimates for the accumulators for typical Swedish rock conditions.

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Eight Ship Proposals pp. 243-245

Projets de Navires à Propulsion Nucléaire.

Un Comité de l'Amirauté examine huit projets différents de réacteurs convenant à la propulsion marine. Parmi ses huit projets, sept émanent de l'industrie et le huitième de l'A.E.A. Après avoir examiné ses projets, le Comité Galbraith donnera son avis au Gouvernement sur l'action à prendre.

Vorschläge für Atom-Schiffe.

Acht verschiedene Entwürfe von Reaktor-Antrieben für Schiffe sind einer Kommission der Admiralität zur Begutachtung vorgelegt worden. Von diesen acht Entwürfen sind sieben von der Industrie unterbreitet worden und ein Entwurf von der AEA (Atomic Energy Authority). Nach Prüfung der Entwürfe wird die "Galbraith" Kommission der Regierung empfehlen, welchen Kurs sie einschlagen sollte.

Las Propuestas Para Barcos a Propulsión Nuclear.

A un Comité del Almirantazgo se han sometido para su consideración ocho diseños distintos de reactor adecuados para propulsión marina. De estos ocho diseños, siete emanan de fuentes industriales y uno de la "AEA" (Autoridad de Energía Atómica). Después de un examen de estos diseños, el Comité Galbraith hará sus recomendaciones al Gobierno con respecto al curso de acción a ser seguido.

Steam Cooling pp. 246-249

Refroidissement par Vapeur.

Un projet pour réacteur soumis par Vickers Nuclear Engineering Ltd. (une Société qui comprend en outre Vickers, Rolls Royce et Foster Wheelers) est basé sur la modération à l'eau lourde et le refroidissement par vapeur. Conçu spécifiquement comme réacteur marin, la sécurité complète est revendiqué pour toutes conditions d'accélération et d'altitude, et il est basé sur des techniques qui ont été mises à l'épreuve.

Dampf-Kühlung.

Reaktor-Entwürfe, die von der Vickers-Nuclear Engineering Ltd. (zu der Gesellschaft gehören ausser Vickers Rolls-Royce and Foster Wheelers) unterbreitet wurden, beruhen auf schwerem Wasser als Moderator und auf Kühlung durch Dampf. Die Entwürfe sind in der Hauptsache für Schiffe gedacht, und es wird versichert, dass volle Sicherheit unter allen Bedingungen vorhanden sei unabhängig von Beschleunigungskräften und Lage, und dass die Entwürfe auf Konstruktionen beruhen, deren Wert sich bereits unabhängig bewiesen hat.

Enfriamiento por Vapor.

Los diseños de reactor sometido por la Vickers Nuclear Engineering Ltd., (una compañía que incluye, además de Vickers, la Compañía Rolls Royce y la firma Foster Wheelers) están basados en moderación a agua pesada y enfriamiento por vapor. Para este reactor, diseñado esencialmente como un reactor marino, se reclama completa seguridad en todas las condiciones de aceleración y altitud, y está basado en técnicas que han sido independientemente comprobadas.

Electronic Instrumentation
For Nuclear Power Plants

By C. W. CAWTHORNE
(*Instrumentation Engineer, Evershed and Vignoles, Ltd.*

In this article the methods of producing the necessary signal for the transmission of information derived from conventional instruments used in monitoring a power reactor system are discussed, in relation to measurement of pressure temperatures, flow, level, density and position.

ALTHOUGH the requirements of an instrumentation system for a power reactor are diverse, they can usually be met with equipment that has been tried and proved in other industries—oil, steel, chemicals, mining, etc. The special conditions encountered in nuclear work may require some " tailoring " of standard units. While pneumatic and hydraulic transmission systems have their adherents, electrical transmission is, in the author's opinion, to be preferred, for the following reasons:—

(1) Transmission errors and time lags are negligible, so that centralized control is facilitated over long transmission distances.

(2) Extreme flexibility of layout is possible.

(3) The use of multi-core cables instead of multiple pipe runs reduces installation and maintenance costs.

(4) Complex functions of the measured variables can be readily generated.

(5) Analogue to digital conversion is easy for data reduction and logging.

(6) The use of cable inter-connections permits the control room to be sealed off from other parts of the reactor plant. There is no danger of contamination in the control room due to a leak in a pneumatic instrument.

The instrumentation system may be considered under three headings, transmitters, panel instruments, and positioners or actuators.

Transmitters.—All transmitters are based on the electronic repeater principle, and differ only in the sensing element, which is changed to suit the type and magnitude of the measured variable. The transmitting loop comprises the transmitter unit and the power unit, this latter unit being installed in the control room.

The principles of the electronic repeater are shown in Fig. 1. It uses force-balance operation, the force produced by the sensing element being continuously balanced by the force produced by the output current.

The force produced by the sensing element—a diaphragm in Fig. 1, is applied to a pivoted beam carrying a coil, operating in the field of a pot magnet. The coil is in the cathode circuit of a triode valve (contained in the power unit), the circuit being completed through the panel instruments, which are connected electrically in series across terminals A and B. At the extremity of the beam is a disc contact, which moves between two fixed contacts connected to sources of positive and negative bias. Any change in the force produced by the diaphragm causes the beam to move, so that the disc contact touches one or other of the biasing contacts. This alters the current through the valve until the force exerted by the coil balances the new force produced by the diaphragm when equilibrium is restored and the contacts break.

The circuit is self-compensating over wide limits, for changes in line resistance, variation of voltage, or frequency of the supply to the power unit; the current through the coil and in the transmission circuit is always maintained proportional to the force produced by the measuring element. The transmitter is essentially a force balancing device, the valve merely acting as an infinitely variable resistor for regulating the current in the pot coil and panel instruments. The valve characteristic is thus of no importance and plays no part in the calibration of the transmitter.

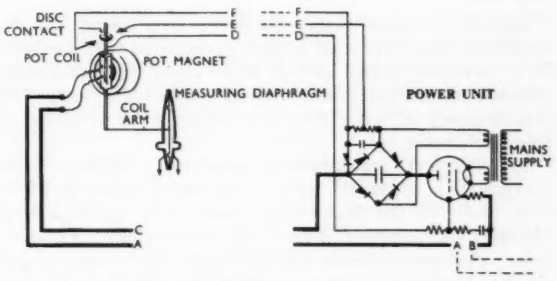


Fig. 1.—Schematic diagram of the electronic repeater using force-balancing and a 5-lead interconnection.

Pressure.—For this application, a stainless steel bellows is used as the pressure sensing element, and the force produced by the pressure acting on the bellows is balanced by the output current using the electronic repeater principle. The output current is then directly proportional to the measured pressure. For critical pressure measurements, a high degree of zero suppression is provided, and it is possible to obtain a scale span of 150 p.s.i. on a measured pressure of 7,000 p.s.i. Over-range protection is also included.

Differential Pressure.—For differential pressure up to 200 in. w.g. a differential diaphragm acts as the measuring element. Here again, the electronic repeater is used to balance the force developed by the diaphragm against the force produced by the output current. For higher differential pressure, a bellows is used as the sensing element.

Flow.—The flow transmitter is based on a differential diaphragm and is similar to the instrument shown in Fig. 1. However, the feedback arrangements are altered somewhat to give square root compensation. The pot magnet is replaced by an electro-magnet, and the winding of the electro-magnet and the feedback coil are energized in series by the output current. The feedback force developed is thus a function of the square of the output current.

At balance, the feedback force equals the force produced by the diaphragm and hence the differential pressure across it. As this differential pressure varies as the square of the measured flow, the output current from the flow transmitter is directly proportional to the measured flow.

This simple arrangement of square root compensation permits the use of indicating and recording instruments with linear scales and allows the flow signal to be integrated and

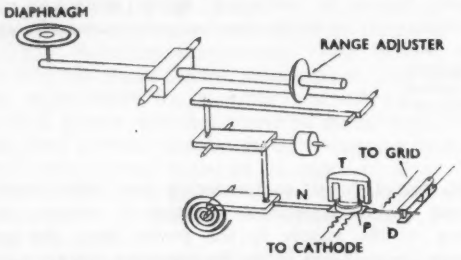


Fig. 2.—Mechanical position indicator where beam N transmits force from instrument spring to coil P operating in field of T. Out-of-balance detected by contacts D.

summated. For example, the gas flow through a number of gas ducts on a nuclear reactor can be summated by merely adding the output currents of a number of flow transmitters, each transmitter measuring the flow through one duct.

Level.—In many cases, the level in a vessel can be expressed as a differential pressure compared with the level in a reference vessel and in these cases, the differential pressure transmitter can be used to measure the level. The measurement of water level in a boiler drum is typical of this application.

In other level measurement problems, a displacer level transmitter is employed, the principle being shown in Fig 4. The body of the transmitter contains a stainless steel displacer (H) attached to beam (K) by a leaf spring suspension. The beam passes through a flexible bellows and is rigidly attached to a pivoted stirrup (N) carrying a toothed quadrant (R).

The beam is connected to a tension spring (T), which acts in opposition to the weight of the displacer, so that the latter is supported partially by the force due to the weight of the liquid displaced and partially by the tension spring. Any change in liquid level upsets this balance resulting in a movement of the beam and toothed quadrant (R).

The quadrant operates a lay shaft moving the pointer (J) of a local indicator and winding up an instrument-type spring (L). The force produced by this spring, which is a measure of the position of the toothed quadrant and hence the level, is balanced by the electronic repeater against the output current. The current output of the transmitter is thus a measure of the liquid level.

The displacer level transmitter, in suitable materials and suitably tailored, has been used to measure liquid sodium level in a reactor plant.

Specific Gravity.—The displacer level transmitter can also be employed for the measurement of specific gravity. For this application the displacer is completely immersed in the fluid and thus the output current from the transmitter is a function of the specific gravity of the fluid.

Mechanical Position.—It is often required to measure mechanical position, e.g., the position of a valve spindle or damper and to transmit this measurement to the control room for indication or recording. This requirement is met by a mechanical transmitter in which a moving mechanism, the position of which is to be transmitted, is linked mechanically to a shaft and countershaft which winds up an instrument-type spring. The force produced by this spring is balanced by the electronic repeater so that the output current is a measure of the position of the shaft (Fig. 2).

Power Unit

Each of the transmitters described works with a power unit which can be installed remotely from the transmitter, and is usually located behind the instrument panel or in the control room. For large instrumentation installations, it is convenient to "rack mount" the units in plug-in form in centralized cubicles. All power units are identical, irrespective of duty, so that spares are reduced to a minimum. With this system, all electronic components are removed from the plant and centralized in the control

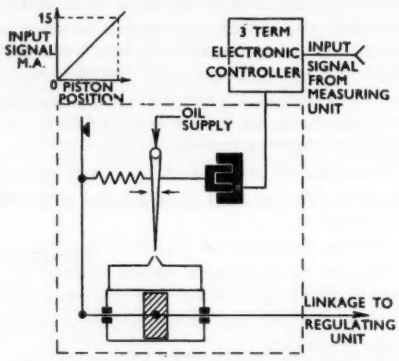


Fig. 3.—Electro-hydraulic valve positioner in which the signal from the electronic controller is caused through a hydraulic linkage to be linearly dependent on piston position.

room, where conditions are conducive to regular and adequate maintenance.

Panel Instruments

Indicators, Recorders and Integrators.—As the transmitted signal is an electrical current varying with the value of the measured variable over the range 0-15 milliamp d.c., the panel instruments are all based on simple robust moving coil movements, and a wide variety of such instruments is available varying in size and shape from miniature to large size. A suitable indicator or recorder can therefore be selected to suit any type of panel layout. For integration, simple milliampere-hour instruments are used.

An interesting development in panel instruments is the In-Line Scanner, whose function is to present to the operator quickly and in a simple form, the state of a comprehensive control scheme. It comprises a number of shadow indicators mounted side by side. These indicators, which show the error in the control circuits, are arranged so that their pointers are in mid-position for zero error. The display for a plant, where all control loops are at zero error, appears as a straight horizontal line—a departure from the desired value at any point. breaks this line and the amount of deflection indicates the magnitude of the error. A plant disturbance is thus immediately obvious to the operator, who can take appropriate action.

Controllers.—The measured value is presented to the electronic controller as a current signal, which is compared in the controller with a reference value—the desired value—to give an error signal. The output of the controller,

again a current signal, containing the proportional, integral and derivative functions of error, is passed to a positioner which operates the regulating unit. This controller is completely electronic in operation, with no moving parts and employs a printed circuit. The control terms are completely non-interacting and the circuitry given " built in " integral limiting.

A feature, which is new to process controller design, gives full testing facilities without either removing the unit from the panel or using external test equipment. By throwing a switch on the front plate, the controller is isolated from the control loop and whilst still maintaining the plant under remote manual operation, the controller loop is completed through a dummy load so that the operation of the unit can be checked and adjusted if necessary.

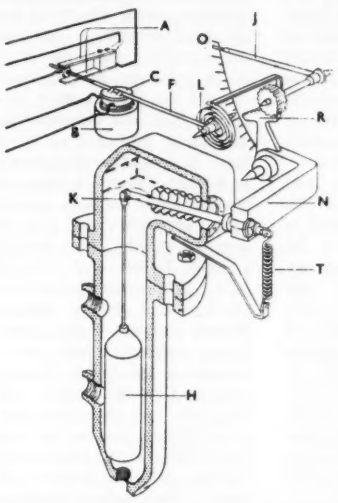


Fig. 4.—Displacer level transmitter, also suitable for transmitting information on density.

Valve Positioners.—The output from the electronic controller is a low power signal and the regulating unit it has to operate is sometimes extremely large, requiring considerable force to overcome inertia, friction and out-of-balance loads. It is usual, therefore, to use a pneumatic or hydraulic actuator to obtain these forces. At present an electric drive is not used, because of the difficulty in obtaining the necessary servo characteristics from electric motors—particularly from the large size motors which are required for positioners, for high-torque and high-speed operation.

Electro-hydraulic Positioners.—The electro-hydraulic positioner is based on the jet pipe principle. The signal from the electronic controller energizes an electro-magnetic thruster of special design which produces a proportional force on the jet pipe, Fig. 3. This causes the jet pipe to deflect and to set up a pressure differential across the operating piston. The piston thus moves and repositions the regulating unit. The position of the piston is fed back through a mechanical linkage to the feedback spring and the compression of this spring and hence the force produced by it is a function of piston position. As the feedback spring force is balanced on the jet pipe by the force produced by the input current signal, a linear input signal/piston position characteristic is obtained. By replacing the simple lever feedback arrangement by a cam and follower, the positioner can be given any desired characteristic.

Electro-pneumatic Positioners.—The electro-pneumatic positioner is normally mounted on the top-work of a diaphragm operated characterized control valve (Fig. 5).

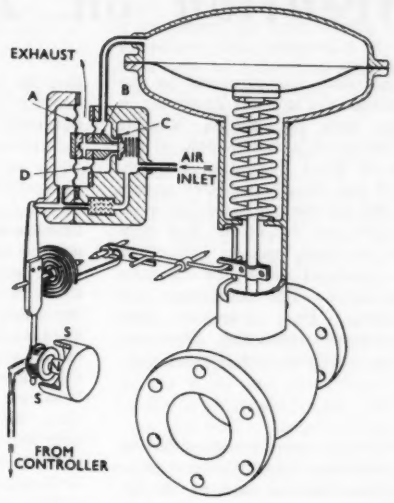


Fig. 5.—Electro-pneumatic positioner in which the air is used as a power medium only.

As in the hydraulic positioner, the force produced by the input current, flowing in a pot coil and magnet system, is balanced against the feedback force, produced by a spring mechanically linked to the spindle of the valve. Any change in the input current upsets this force balance and by means of a flapper and nozzle system alters the air pressure on the diaphragm motor. This causes a movement of the valve spindle to regain the force balance. The position of the valve spindle is thus continuously compared with the value of the input current signal—the air being used only as the power medium and playing no part in the calibration of the positioner.

Die Ausstattung von Kernkraftwerken mit elektronischen Instrumenten

Die Uebermittlung von Werten, die von im wesentlichen konventionellen Instrumenten angezeigt werden, wie sie bei der Ueberwachung von Kernkraft-Reaktoren benutzt werden, geschieht am besten auf elektrischem Wege. Die Methoden, mit denen man das erforderliche Signal gibt, werden in Bezug auf die Messungen von Druck, Temperatur, Fliessgeschwindigkeit, Flüssigkeitsstand, Dichte und Stellung diskutiert. Sichtbare Anordnung wird dann besprochen, gefolgt von einer kurzen Notiz über Betätigungs-Mechanismen.

Instrumentación Electrónica para Centrales de Fuerza Nuclear

La transmisión de información derivada de los sustancialmente convencionales instrumentos empleados en la supervisión de un sistema de reactor de fuerza, puede hacerse mejor eléctricamente. Los métodos de producir la señal necesaria se discuten en relación a medidas de temperatura de presión, flujo, nivel, densidad y posición. Acto seguido se considera el factor de exposición, con una breve nota sobre accionadores.

Instrumentation Electronique pour les Installations d'Energie Nucléaire

Le meilleur moyen d'effectuer la transmission des informations dérivées d'instruments substantiellement traditionnels employés pour le contrôle d'un système de réacteur d'énergie, c'est électriquement. Dans le mémoire on examine les méthodes de production du signal nécessaire en rapport avec les mesures de pression, température, écoulement, niveau, densité et position. La représentation y est ensuite considérée, et est suivie de notes brèves sur les dispositifs activateurs.

Convention on Thermonuclear Processes

THE conference was arranged by the Institution of Electrical Engineers in conjunction with the British Nuclear Energy Conference and was held at the Institution of Civil Engineers, London, on April 29 and 30. Twenty-two papers (see page 268 for the complete list) were presented and one, by D. W. Fry published for the first time in December, 1958, was circulated among the delegates in printed form. The conference was well attended. Fifty delegates from overseas countries including Germany, the Benelux countries and Russia, were present.

Research

The conference opened with a lecture by *T. E. Allibone* which in a manner was complementary to that of D. W. Fry, the former dealing first of all with the fundamental and theoretical aspects of the problems involved and the latter with the outcome of practical experimental work. Allibone after restating the object of thermonuclear research and defining the basic phenomena of the reaction concentrated on a discussion of the losses and the various avenues of approach to effective containment of the plasma. He comes to the conclusion that theory does not fully describe plasma behaviour in practice. There still exists an unknown mechanism, whereby electrons at a certain energy level lose energy momentum to the walls very rapidly. This mechanism may be in the nature of magnetohydrodynamic instability, in which case time-programmed stabilizing fields may help, or it could be due to plasma oscillations excited by fast runaway particles.

D. W. Fry's conclusions concur with the above. Dealing with the pinch he states that the stability theory for pinches with volume current distribution is in a less advanced state than is the case where the current might be considered as being on a surface. Up to the present no improvement of stability has been predicted for the slower pinches and the theories are unable to explain the plasma confinement that has been observed in Zeta and Sceptre, both of which are slow-pinch devices. In the case of Zeta, the magnetic field fluctuations seemed to increase as the contaminant gases present in the system decreased, suggesting that the plasma became more unstable. Whatever pinch system is used, fast or slow, there is always a large unaccountable energy loss present. The Stellarator, a machine not using the pinch and designed to effect containment by the application of external magnetic fields, is not fully explored yet as most of the experimental work was directed to the initial joule heating stage. The time taken for the plasma to reach the walls was observed to be several orders of magnitude less than theory predicts. Also, instead of being proportional to the square of the magnetic field, the time appears to be proportional to the square root. The author concludes that there is not yet available a sound operational model for thermonuclear power generation.

A paper of special interest is that by *J. E. Jukes* who investigates the possibility of converting directly nuclear energy released by controlled fusion into electrical energy. While indirect conversion appears obligatory in the case of the fission reactor, the nature of the various thermonuclear fusion devices under consideration at present suggests that direct conversion is possible and may have considerable advantages. For instance, it may be possible to obtain a high thermodynamic efficiency with a consequent saving in bulk and cost of the intermediate heat exchanger plant. During the operation of a thermonuclear reactor energy escapes from the plasma as bremsstrahlung, energetic neutrons and other charged and neutral particles. All this energy may be converted indirectly to electrical power but, in addition, some electrical power may be extracted directly. The treatise is based on a reactor working on the stabilized pinch principle. By employing modulated current the plasma may be adiabatically compressed and expanded by alternately increasing and decreasing the confining field. At maximum compression the plasma is hottest, fusion is most rapid and the plasma takes in heat energy. At maximum expansion the loss of heat (presumed mainly by radiation cooling) exceeds fusion and the plasma rejects heat. The plasma pressure and discharge current are closely coupled. As the plasma expands it does work on the confining magnetic field and this appears directly as energy in the external circuit proposed by the author and shown in a diagram. As the discharge is a source of electrical power, the current oscillations will grow in amplitude. The power surplus can be drained off in various ways. The author compares sinusoidal modulation of the discharge current and square modulation, and proves that only the latter would give beneficial results. In theory, about one third of the available energy may be extracted directly.

Devices

A series of papers was concerned with the design and performance of, and investigation work in, specific research apparatus. *A. A. Ware* described Sceptre

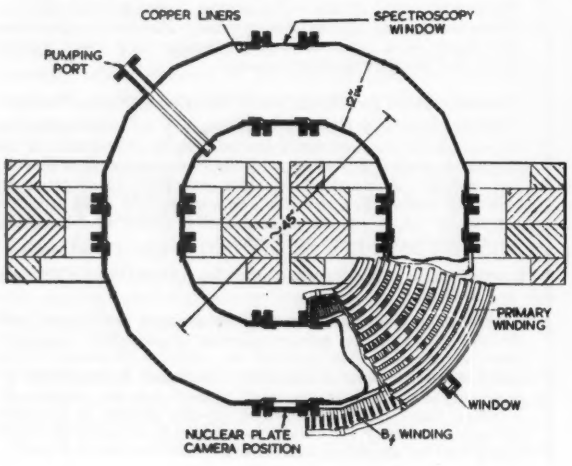


Fig. 1. (Left)—Schematic of Sceptre IIIA.
Fig. 2. (Above)—Liner assembly in torus.

IIIA. Experience in operating Sceptre III indicated discrepancies between calculated and measured values for certain quantities such as electron temperature. In order to facilitate further measurements on the discharge, two major alterations were carried out: a new set of 208 single-turn water-cooled coils was fitted in order to obtain larger magnetic fields and a higher discharge repetition rate. Secondly, two of the straight sections in the torus were replaced by sections 2 in. longer than before, making each 7.5 in. long. One of the new sections contains a quartz window which enables observation of the discharge tangentially in a parallel and anti-parallel direction of the gas current, as well as radially. Oscillogrammes taken of gas current and voltage have shown that the waveforms in Sceptre IIIA are the same as in Sceptre III. So is the peak gas current for a given set of conditions.

Initial results of work carried out with the new facilities are reported. A method of measuring electron temperature from the absolute intensity carbon V spectrum has been devised (and is discussed in greater detail in the paper presented by *R. M. Payne* and *S. Kaufman*) yielding a value of 2.5×10^5 °K, which is believed to be of the correct order of magnitude. Further, the "bars" observed on streak photographs have been investigated. When the discharge is running under clean conditions, the only part of the tube which emits visible light is that between the discharge core and the walls. The light appears intermittently and often as a series of bars at right angles to the streak direction. During the first half-cycle the bars move along the discharge tube in the opposite direction to the positive gas current. Later in the half cycle the direction of movement is sometimes reversed. There is evidence that the electron loss is concentrated on those parts of the tube wall into which lines of magnetic force pass from the discharge space. If a mechanism was known to exist whereby electrons can pass across the magnetic field and reach these particular lines of force, it could be shown that any region of higher density in the discharge would have a reversed component of electric field within it, thus causing the electrons to drift outwards. In this interpretation of events the bars of light observed on the streak photographs may be such regions of higher density. If applicable, the problem of the electron energy loss would thus reduce to the question: what is the cause of the bars?

R. S. Pease spoke on behalf of the Zeta team on the main design parameters of Zeta I, the principal observations made with it up to April of last year and the deductions on the physical phenomena occurring in the hot gas. Typical features of Zeta are the following: Both inductance and magnetic-search coil measurements show that the current channel is constricted in the centre of the discharge tube and the stabilizing field is enhanced by a factor of about 10. The stabilizing field is not trapped by currents

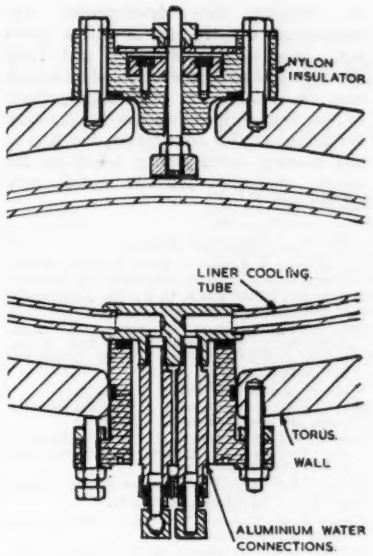
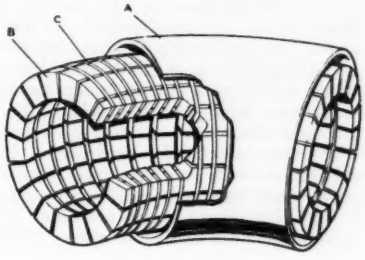


Fig. 3.—Detail of liner supports.

flowing only on the surface of the plasma but the observed distribution of the magnetic field is still to be explained. The efficiency of Zeta as a thermonuclear reactor, in terms of the Lawson product $n_i \Delta t_2$, is about 10^{10} sec-ion/cm³, compared with a value of 10^{16} sec-ion/cm³ required for a power-producing thermonuclear reactor using deuterium-deuterium as the fuel. Zeta is capable of considerable further development, ultimate limits imposed by heat loading of the walls and the available flux swing in the transformer core have not yet been approached. Currents of up to 1 MA should be obtainable by increasing the capacitor bank. The limiting factor so far has been the insulation of the liner system.

Details of the Zeta I vacuum equipment were given by *J. Blears* and *E. J. Greer*. The system to be pumped consisted of a toroidal tube 42 in. bore by 11 ft mean diameter fabricated from 1-in. aluminium plate with a 48-section insulated interleaved water-cooled liner made from ¼-in. aluminium sheet. The liner sections were water-cooled to remove a mean power of 50 kW. Each section comprised two cylinders rolled and spun from ¼-in. thick aluminium sheet welded

Fig. 4.—Segmented liner.



on either side of a central water-cooled tube. The inside diameter of the liner was made as large as possible consistent with the clearance between liner and torus shell, which should not be less than ¼ in. Since the liner cooling tubes were *in vacuo* when assembled in the torus, they were all leak-tested after welding by the mass spectrometer method. The Fig. reproduced on the left shows the method of supporting each section at the top and bottom on nylon insulators sealed to the torus shell by Neoprene O-rings. The cooling water connections were taken through the bottom insulator and jacking screws were provided to adjust the vertical position of the liner section. The torus was split vertically, each half-torus being mounted on a trolley with its vacuum pumps and ancillaries and arranged in such a way that the whole system could be withdrawn from the transformer core for servicing or modification. The specified leak rate was 3 lusecs at a base pressure of 10^{-6} mm Hg.

A better base pressure was one of several improvements it was considered desirable to embody in the Zeta design. An account of these alterations, now completed, is given in a paper by *J. T. D. Mitchell et al.* One of the most important alterations is that of the liner system. Following a suggestion made first by Thonemann to provide a continuous liner of sufficient resistance to ensure that its shunting effect on the discharge was small and consequently breakdown of the main gap in the torus body would be inhibited, stainless steel 0.015 in. thick was chosen as the liner material. In sheet form the material has a low resistance. In order to improve this and, in addition, its strength, the material was corrugated prior to installation. During operation the liner is heated and at a temperature of 255°C its electrical resistance is 0.025 ohm. An illustration showing the liner assembly in the torus is reproduced on page 266. Provision of a continuous liner separating the discharge channel from the torus walls has several advantages from the vacuum engineering point of view. To mention only two: separate pumping of the interspace reduces atmospheric leaks into the discharge channel and thus contamination of the discharge. Secondly, heating of the liner accelerates outgassing and thus reduces the ultimate pressure obtainable. Although all potential advantages have not been fully realized, the base pressure has in fact been reduced to $2\text{-}4 \times 10^{-7}$ mm Hg and the pressure in the liner-torus interspace is about four times lower than that in the discharge channel at operational level, i.e., 10^{-4} mm Hg.

A. E. Robson and *R. Hancox* discussed the important considerations governing the choice of materials and methods of construction. Thermal evaporation characteristics, sputtering performance and the risk of arcing are examined. It appears that for stable discharges of long duration, thermal evaporation and sputtering should not be serious, if materials

of low atomic number are used. In the more severe transient initial conditions, sputtering may limit the duration of the first stage of the discharge. In general, metals are superior to insulators in terms of thermal properties and ease of fabrication, but tend to form "unipolar" arcs when exposed to plasma. As the formation of unipolar arcs is largely a function of the area exposed, it is recommended to employ the so-called segmented liner system. An example of such a liner is shown in an illustration on page 267. The liner is constructed from a series of closely spaced washers, separated by insulators, set well back in the gaps to avoid contact with the plasma. For tubes of the Zeta type the area of each segment should not exceed 1 cm^2 and the gap between segments should not be larger than 0.5 mm.

Electrical Auxiliaries

A number of papers are of special interest to the electrical engineer. *M. A. Bird* describes the design of a compressed-air-operated mechanical switching system specially designed for the Zeta circuit but now superseded by ignitron switching. *H. de B. Knight* reports on the properties and performance of sealed-off ignitrons giving provisional ratings for the 5-in. and 8-in. diameter type. *D. L. Smart* investigates generally the present position with regard to switching requirements in nuclear research. He shows that there is a considerable variety of switches available and refers in particular to the usefulness of ignitrons, but there are applications which cannot be met by existing switches and which will soon require new types. Therefore, considerable development work is carried out at present in various directions. Examples of this work include the development of systems of simultaneously triggered off spark gaps for up to 100 kV d.c., the development of low-pressure spark gaps to provide clamping switches for very high current fast discharges, the development of accurately timed fast mechanical switches having random variations in closing time of $\pm\frac{1}{4}$ msec or less and studies of inductive-store circuit-breakers.

Finally, *R. Carruthers* examines the various methods of storing energy in the form of electric charge, magnetic flux, mechanical or chemical energy. It is shown that storage as electric charge in a capacitor is the most suitable where a rapid discharge is required. Magnetic storage as current in an inductance has its greatest usefulness where energy is required for periods of millisecs and machines and batteries are more appropriate to the longer pulses. So far, capacitor energy storage is the only method which offers a minimum of losses but at a considerable cost compared with other methods of energy storage, where there is considerable power loss during storage time. At the rating assumed in the paper it is possible to make energy storage capacitors at a cost of 3-4d./J which may be reliably charged and discharged several million times.

As is indicated by the report above, no startling new development was announced: containment is still a problem, loss mechanisms are not fully explored and the production of adequate heat on a sufficiently large scale persists in meeting with difficulties in practice. Nevertheless, this convention, the first in this country concentrating solely on the fusion process, proved useful and attractive.

List of Papers

Fry, D. W.: A Review of Work Towards Nuclear Energy from Controlled Thermonuclear Reaction.

Allibone, T. E. and Chick, D. R.: The Basic Physics of Thermonuclear Processes.

Butt, E. P., Carruthers, R., Mitchell, J. T. D., Pease, R. S., Thonemann, P. C., Bird, M. A., Blears, J. and Hartill, E. R.: The Design and Performance of Zeta.

Ware, A. A.: Scepre IIIA.

Payne, R. M. and Kaufman, S.: Physical Measurements on Heavy-current Discharges.

Robson, A. E. and Hancox, R.: Choice of Materials and Problems of Design of Heavy-current Toroidal Discharge Tubes.

Blears, J. and Greer, E. J.: Vacuum System Design.

Bird, M. A.: Switching and Control.

Hartill, E. R.: The Zeta Transformer and Auxiliary Circuit Equipment.

Mitchell, J. T. D., Whittle, H. R., Jackson, E. M. and Clarke, P. B.: The Modification of Zeta in 1958.

Van Atta, C. M.: Thermonuclear Research in the U.S.A.

Golovin, I. N.: Investigations on the Trapping of Fast Charged Particles by Constant Magnetic Fields, Carried out as Part of the U.S.S.R. Thermonuclear Programme.

Tosswill, C. H. and Hope, E. L. V.: The Calculation of Discharge Currents in a Torus with a Continuous Conducting Liner.

Smart, D. L.: Some Switching Problems in Thermonuclear Research.

Fitch, R. A. and McCormick, N. R.: Low-Inductance Switching Using Parallel Spark Gaps.

Knight, H. de B., Herbert, L. and Maddison, R. C.: The Ignitron as a Switch in High-Voltage Heavy-current Pulsing Circuits.

Carruthers, R.: Transformer Design for Toroidal Discharge Systems.

Bickerton, R. J.: A Brief Review of the Toroidal Stabilized Pinch.

Niblett, G. B. F.: Rapid Compression of a Plasma with Azimuthal Currents.

Liley, B. S.: The Circuit Dynamics of Plasma.

Carruthers, R.: Energy Storage for Thermonuclear Research.

Jukes, J. D.: Possibilities of Direct Energy Conversion from Fusion Reactors.

Fitch, R. A.: Rapid Heating for Controlled Fusion Research.

PAPERS OF GENERAL INTEREST

The Development of High-temperature Nuclear Reactors and Medium-size Nuclear Power Plants. By G. B. R. Feilden. (Paper delivered to the Eastern Graduates Section of the Institution of Mechanical Engineers in April, 1959.)

A brief survey was made of the existing types of gas and liquid-cooled reactors and of the prime movers associated with them. This was followed by an examination of the problems involved in the development of gas-cooled reactors capable of giving coolant outlet temperatures of 700°C and higher, which would make the economic use of gas turbine prime movers possible. The potential advantages of such a system were then discussed, particularly in connection with medium-sized power plant which may be required to operate in locations where large quantities of cooling water are difficult to obtain. The various safety problems which will arise in the operation of power plants of this type were outlined, and the possible use of a fully sealed closed-cycle gas turbine alternator with the rotor supported on gas bearings, was described. In conclusion, an estimate was given of the time likely to be required for the various stages in the development of the high-temperature gas-cooled reactor and it was stated that the latter will probably not be ready for commercial application until after the middle of the 1960 decade.

The Industrial Use of Radio-active Isotopes. By N. H. Lowden. (Paper delivered to the South-west London Branch of the Association of Supervising Electrical Engineers in April, 1959.)

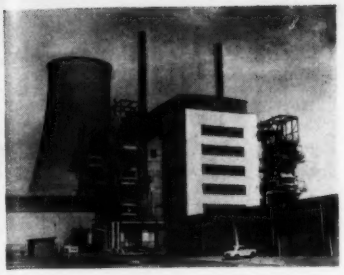
After reviewing generally the nature and properties of radio-active isotopes the lecturer examined instruments employing radiation operationally. Various forms of static eliminators were mentioned as representative examples of alpha radiation instruments, radium being the source of energy. Typical beta radiation instruments are beta-ray thickness gauges and package monitor level gauges, the latter being used for the inspection of correct filling in cartons, cans and other containers. Finally, a description was given of a density gauge using gamma absorption, and various on/off and continuous level indicators employing the same form of radiation. The lecturer concluded with a discussion of the hazards associated with the handling of isotopes in industry and possible means of minimizing the risks.

Characteristics and Performance of Nuclear-powered Submarine Cargo Vessels. By J. A. Teasdale. (Paper presented to the North East Coast Institution of Engineers and Shipbuilders in April, 1959.)

There has been much public interest recently in the possibility of the underwater carriage of cargo but, although submarine cargo vessels are now technically feasible with the use of nuclear power, they are not likely to be used commercially for normal trades unless they can show an economic advantage. The purpose of this paper is to discuss the likely characteristics and performance of a submarine tanker and to compare it with a surface tanker of the same deadweight, both being nuclear propelled.

At normal speeds the optimum submarine form would have a slightly lower resistance than the surface vessel but the margin is such that the saving in annual fuel bill is most unlikely to be offset by the additional cost of a submarine and the operational difficulties.

Operation at higher speeds may become economic if nuclear fuel and machinery costs are reduced to low values, but only when the surface vessels have reached the limit of development for high speed operation is the possibility of submarine cargo vessels likely to be given serious consideration.



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Principal Contractors

ABERDARE ENGINEERING: Decontamination vats.
ACCURATE RECORDING INSTRUMENT CO.: Pressure gauges.
AIR CONTROL INSTALLATION, LTD.: High pressure assemblies.
THE AIRSCREW CO. AND JICWOOD, LTD.: Ducting.
AIRVAC VENTILATING CO.: Ventilating fans.
AITON AND CO., LTD.: Piping.
ALBANY ENG. CO.: R.V. pumps.
W. H. ALLEN AND SONS, AND CO., LTD.: Circulating pumps.
ANDREW MACHINE CONST. CO.: Ducting.
ANGLE TRUCK CO.: Industrial hand trucks.
ARENS CONTROLS: Damper controls.
AUXILIARY HOISTING EQUIPMENT: Hoisting equipment.
BABCOCK AND WILCOX, LTD.: Main heat exchangers, cooling pond cranes, air piping.
SIR W. H. BAILEY AND CO., LTD.: Globe valves, low pressure valves.
BARR AND STROUD: Inspection lamps.
BATES BROS.: Ducting and shields.
BAYHAM, LTD.: CO_2 gauges.
J. BELL AND CROYDON, LTD.: High pressure sterilizer.
F. W. BERK AND CO., LTD.: Shot blasting.
HENRY BERRY: Hydraulic lifting tongs.
BIDE TRANSFORMER CO.: Underwater lighting.
J. BLAKEBOROUGH AND SONS, LTD.: Valves.
WILLIAM BOBY AND CO., LTD.: Make-up de-aerators.
J. BOYD AND CO., LTD.: Crane.
F. BRABY: Oil tanks.
BRITISH ERMETO CORPN., LTD.: Valve.
BRITISH INSULATED CALLENDER'S CABLES, LTD.: Cables.
B. I. CALLENDER'S CONSTRUCTION CO.: Electrical supplies.
BRITISH OXYGEN ENGINEERING, LTD.: CO_2 regulator.
BROOKHIRST SWITCHGEAR, LTD.: Auxiliary starters.
BROOM AND WADE, LTD.: Air compressors and equipment.
BRUSH ELECTRICAL CO., LTD.: Transformers.
BURNETT AND LEWIS, LTD.: Air drier.
CAMBRIDGE INST. CO.: Thermometers.
CARBON DIOXIDE CO.: Evaporation plant.
CHATWOOD SAFE: Discharge chamber doors.
CLYDE FUEL SYSTEMS: Servicing of equipment.
COCHRAN AND CO. ANNAN, LTD.: Boilers.
G. COHEN: Electric hoist.
COLVILLES, LTD.: Reinforcing bars.
CONTACTOR SWITCHGEAR: Contactor starters.
CONVEYANCER FORK TRUCKS, LTD.: Fork lift trucks.
L. J. COUVES AND PARTNERS: Architects.
J. A. CRABTREE AND CO., LTD.: Auxiliary starters.
CRANE PACKING, LTD.: Condenser tube cleaning equipment.
CRAVENS, LTD.: Skips.
CRESSAL MEG. CO., LTD.: Rheostats.
CROMPTON PARKINSON, LTD.: Stud welding equipment.
DARLINGTON INSULATORS: Insulators.
DARROLD ENG.: Roller conveyor track.
DAVEY, PAXMAN AND CO., LTD.: Casing for valves.
DELAPENA AND SON, LTD.: 20 kW generator.
G. P. DENNIS, LTD.: Switchboard.
DEWRANCE AND CO., LTD.: P.S. valves.
D.E.V. ENG.: Butterfly valve.
DEXION, LTD.: Racks for metal components.
THE DISTILLERS CO., LTD.: CO_2 storage and evaporation plant, CO_2 vaporizer.
DISTINGTON ENGINEERING CO., LTD.: Transport coffins.
DORMAN LONG, LTD.: Rolled steel sections.
DOSING AND FILTERING EQUIPMENT: Dosing and filtering equipment.
EMPYRIUM WELDING AND MFG. CO., LTD.: CO_2 receivers.
THE ENGLISH ELECTRIC CO., LTD.: Switchgear.
ENGLISH STEEL TOOL CORPORATION, LTD.: Automatic coupler.
ESSO PETROLEUM CO., LTD.: Fuel oil.
EVANS LIFTS: Lifts.
FAIRLEEDE ENGINEERING: Boiling mechanisms.
FILM COOLING TOWERS (1925), LTD.: Cooling towers.
ALEX FINDLAY AND CO., LTD.: Steel frame buildings.
GENT AND CO., LTD.: Fire alarms.
HACKBRIDGE AND HEWITTIC ELECTRIC CO., LTD.: Reactors.
G. N. HADEN AND SONS, LTD.: Fuel oil storage tanks.
HADFIELDS, LTD.: Containers for control rods.
MATTHEW HALL AND CO., LTD.: Pipework.
HENRY HARGREAVES AND SONS, LTD.: Ducting and leading.
HICK HARGREAVES AND CO., LTD.: De-aerators, etc.
HARMER AND SIMMONS: Stand-by auto-charger.
HAYWARD TYLE AND CO., LTD.: Circulating pumps.
W. T. HENLEY, LTD.: Distribution pillars, cables.
HOLDEN AND BROOKE: Pumps.
HOPKINSONS, LTD.: Non-return valves.
JAMES HOWDEN AND CO., LTD.: Fans.
IGRANIC ELECTRIC CO., LTD.: Hoists and cranes.
INTERNATIONAL GAS DETECTORS, LTD.: CO_2 indicators.
ROBERT JENKINS AND CO., LTD.: Sluice valves.
JONES, TATE AND CO.: Valves.
GEORGE KENT, LTD.: Steam meter.
J. KERR: Fire-fighting equipment.
THE WALTER KIDDE CO., LTD.: Fire-fighting equipment.
GEO. W. KING, LTD.: Manual hoists.
KLEEN-E-ZE BRUSH CO., LTD.: Condenser tube cleaning equipment.
LANCASHIRE DYNAMO NEVELIN, LTD.: Motors.
LEYLAND MOTORS: Tip chassis.
E. N. MACKLEY AND CO.: Special tools for ponds.
MACKNIGHT MOTORS, LTD.: Tractor and trailer.
MAGNETO TIME CO.: Time recording clocks.
MATHER AND PLATT, LTD.: Fire fighting and alarm installations.
MECHANISM, LTD.: Blow down receiver.
MERZ AND McLELLAN: Main civil engineering consultants.
METERING PUMPS: Dosing equipment.
METROPOLITAN REFRIGERATION, LTD.: CO_2 storage tanks.
THE MITCHELL CONSTRUCTION CO., LTD.: Main civil engineering work.
W. AND E. MOORE, LTD.: Electric hoist blocks.
HERBERT MORRIS, LTD.: Chain blocks.
MUNRO AND MILLER, LTD.: Oil fuel storage tanks.
NECKAR WATER SOFTENER: Coffin and basket decontamination.
NEGRETTI AND ZAMBRA, LTD.: Indicators.
NEW WESTERN (ENGINEERING), LTD.: Installation, testing and commissioning of instruments.
NORTH EASTERN RADIOGRAPHY: Radiographing.
W. AND C. PANTIN: Roller conveyor.
C. A. PARSONS AND CO., LTD.: Turbo-generators.
T. B. PEARSON AND SONS, LTD.: Air ducts.
THE PERMUTIT CO., LTD.: Water treatment plant.
PLESSEY NUCLEONICS, LTD.: B.S.D. gear.
PNEUMATIC COMPONENTS: Air-line couplings.
POWELL DUFFRYN CARBON PRODUCTS, LTD.: Trepanning cutters.
PYE, LTD.: Multi-purpose cameras.
RANSOMES AND RAPIER, LTD.: Mobile crane.
RICHARD KLINGER, LTD.: Piston valves, Klingerit " joints."
RICHARD LLOYD: Boring tools.
REAVELL AND CO., LTD.: Gas booster and compressors.
THE RECORD ELECTRICAL CO., LTD.: External resistance.
REDHEUGH IRON AND STEEL CO. (1936), LTD.: Oil storage tanks.
REYROLLE AND CO.: Erection of switchgear.
ROYCE ELECTRIC FURNACES, LTD.: Drying ovens.
SHAW AND McINNES, LTD.: Cast iron special pipe.
SHELL-MEX AND B.P., LTD.: Fuel oil suppliers.
SIEMENS, EDISON SWAN, LTD.: Cable racking.
SIMPLEX ELECTRICAL CO., LTD.: Terminal boxes.
THE STANTON IRONWORKS CO., LTD.: Special pipes and joints.
STEELS ENGINEERING PRODUCTS, LTD.: Mobile crane.
STEWARTS AND LLOYDS, LTD.: Main pipework contractors, piping.
R. B. STIRLING AND CO., LTD.: Ducting.
STRINGER (CRADLEY HEATH), LTD.: Jib crane.
SULZER BROS., LTD. [LEEDS]: Feed pumps.
TARSLAG: Effluent drain.
TAYLOR WOODROW CONSTRUCTION, LTD.: Preliminary and original works.
JOHN THOMPSON INSTRUMENT CO., LTD.: CO_2 static tanks.
TRANSFORMERS (WATFORD), LTD.: Transformer.
TRESS ENG.: Globe valve.
RONALD TRIST AND CO., LTD.: Feed water regulators.
VAUGHAN CRANE CO., LTD.: Crane (cooling pond).
VERSIL, LTD.: Heat insulators.
VOKES, LTD.: Oil filters, etc.
JAMES WALKER AND CO., LTD.: Gaskets.
THOS. W. WARD, LTD.: Installation plant and machinery.
WERT'S GAS IMPROVEMENT CO., LTD.: Sludge container coffins.
THE WHARTON CRANE AND HOIST CO., LTD.: Cranes.
WHESSOE, LTD.: Reactor pressure vessels.
WHIPP AND BOUNE, LTD.: Blower motors.
WILLIAMS AND JONES (ENGINEERS), LTD.: Air receivers.
WOLSELEY HOLDINGS, LTD.: Boating of decontamination vats.
YORK SHIPLEY, LTD.: Condensing units.
YORKSHIRE ELECTRIC TRANSFORMER, LTD.: Transformers.
YORKSHIRE IMPERIAL METALS, LTD.: Copper tubes.

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La deuxième centrale d'énergie nucléaire de Grande Bretagne a été inaugurée officiellement le 2 mai. Presque identique à celle de Calder Hall—il y a quatre réacteurs, qui développent chacun 200 mw (t) et 46 mw (e). La centrale diffère surtout dans le fait qu'elle pourvoit des réservoirs de refroidissement pour les éléments actifs. Actuellement, un des réservoirs est en marche, le deuxième doit devenir critique prochainement et la centrale devra donner son plein rendement l'année prochaine.

Chappelcross.

Das zweite britische Kernkraftwerk ist am 2 Mai offiziell eröffnet worden. Es ist praktisch identisch mit Calder Hall—vier Reaktoren sind vorhanden, die nach Fertigstellung jeder 200 MW (t) und 46 MW (E) entwickeln können. Das Werk weicht in der Hauptsache darin ab, dass Kühlteiche vorgesehen sind, um aktive Elemente zu lagern. Zur Zeit ist ein Reaktor unter Dampf, ein zweiter wird in kurzem kritisch werden, und das Werk wird im nächsten Jahr in vollem Betrieb sein.

Chapelcross.

El dia 2 de mayo fué inaugurada la segunda central de fuerza nuclear de la Gran Bretaña. Prácticamente idéntica a Calder Hall—hay cuatro reactores que cuando completas producen cada uno 200 MW (t) y 46 MW (E). La central difiere principalmente en la provisión de estanques de enfriamiento para almacenamiento de elementos activos. Actualmente, hay un reactor generando vapor, el segundo está a punto de volverse crítico en cualquier momento y la central debe estar en pleno funcionamiento el año que viene.

O.E.E.C. Conference at Stresa on

Over 500 delegates recently spent a week in Stresa, Italy, discussing the industrial prospects of nuclear energy in Europe. Special attention was paid to managerial and administrative problems and the potential market for nuclear components.

WHATEVER Europe may lack in finance or nuclear know-how, there is certainly a great determination to push ahead with an industrial programme for the development of nuclear energy. That, at any rate, was one of the most striking impressions of the conference arranged by O.E.E.C. and held in Stresa, Italy, from May 11 to 15. The conference—the third of a series dealing with industrial prospects of nuclear energy—was attended by over five hundred delegates drawn from industrial companies and atomic energy authorities in twenty Western European countries, U.S.A. and Canada.

There are so many conferences on nuclear energy nowadays that it is pertinent at this stage to ask why O.E.E.C.'s European Nuclear Energy Agency should take the trouble to promote one. In point of fact, before the Agency was formed in December, 1957, O.E.E.C. had already organized two similar meetings in Paris (April, 1957) and Amsterdam (June, 1957). The common purpose behind all three conferences was the promotion of collaboration in nuclear matters between the 17 O.E.E.C. countries.

As background to Stresa, ENEA staff have during the past few months, prepared a remarkable series of reports showing on the one hand the probable influence of nuclear energy on the European way of life and, on the other, to suggest possible contributions that European industry could make to the development of nuclear energy. These reports—listed separately on this page—did indeed form a useful starting point for the discussions. That is not to suggest that they were perfect or complete—in compiling a final draft on each subject the Agency intends to make use of the discussions at Stresa and any other representations which interested parties may make.

Obviously one cannot at this point make a final assessment of the value of the conference. Delegates who expected momentous decisions on new reactor types as at Geneva last year were bound to be disappointed. The essential purpose of Stresa was to point the way ahead from an administrative or managerial viewpoint. This was achieved simply by reviewing progress in various countries—notably the U.S.A. and the U.K.—to see how the knowledge already acquired could best be applied for European needs.

The conference was divided into eight main sessions, the first day being devoted to a survey of European programmes and consideration of the economics of nuclear power. On the second day simultaneous discussions were concerned with financing of programmes on the one hand and the market for materials on the other.

Similarly on Wednesday, May 13, atomic law and the market for equipment were discussed at separate meetings whilst the following day was taken up with the market for instruments and management problems. The final two days were spent on visits to Italian nuclear research establishments.

Opening the first session in Stresa's magnificent new conference hall, Professor L. Nicolaidis, chairman of the European Nuclear Energy Agency steering committee, briefly reviewed the Agency's work: it was now contributing to three major projects with a total cost of $60 million, he said. These schemes were (a) the Eurochemic plant at Mol, Belgium ($20 million), (b) assistance for the Halden boiling heavy water reactor in Norway ($4 million over three years) and (c) contributions to the Dragon high temperature gas-cooled experimental power reactor at Winfrith Heath ($38 million).

Apart from these projects, the Agency was also playing an important part in the provision of training facilities for European nationals. As well as the reactor courses at Harwell and Saclay it was hoped to inaugurate University training soon.

Professor Nicolaidis commented that progress in the adoption of nuclear energy in Europe could be made only if the various nations were prepared to work together: industry itself must shoulder the heavy task of spreading knowledge in both the economic and technological fields.

Appropriately enough, considering the location of the conference, the first lecturer was Prof. Ing. C. Matteini of SENN. Evaluating European nuclear energy programmes, he referred to the different rôles of such organizations as CERN, IAEA, ENEA and Euratom.

In assessing future prospects he thought it most important to consider the relative availability of either enriched uranium or natural uranium. The importance of the recent Euratom-U.S. agreement was that it guaranteed a supply of enriched uranium for Europe at an agreed price. Quoting from an O.E.E.C. paper, he mentioned reactor systems most likely to interest Europe as: (1) natural uranium gas-cooled, graphite-moderated, (2) uranium oxide, heavy water moderated, (3) PWR, (4) BWR, (5) fast breeders, (6) AGR, (7). HTGC systems, (8) slightly enriched OMR.

In his opinion, a most important step would be a reduction in capital cost which he felt could be obtained by a simplification of the instrumentation once the design of a particular type of reactor had become established.

The next speaker, Sir William Cook, of the U.K. AEA, who spoke about the first generations of nuclear power stations, contrasted developments in three countries, U.S.A., France and the U.K. Of the American systems, Sir William thought the BWR was the most promising in view of the possibility of a direct cycle, thus avoiding the need for heat exchangers. There was, he said, growing evidence to justify confidence in uranium oxide fuel elements some of which had already been subjected to periods of irradiation corresponding to more than 10,000 MWd/t.

By and large, however, reports from France confirmed our own experience that, for countries without sufficient cheap electric power to enrich uranium, the natural uranium, graphite moderated, gas-cooled reactor was the most promising. Since it went on load in 1956, Calder Hall had generated a total of 1,000 million kWh. Very little trouble had been experienced with the Calder power unit which, in many respects, was less difficult to commission than conventional plant. Operating as a base load station, Calder had achieved a load

O.E.E.C. PUBLICATIONS

Estimates of Nuclear Energy Production in Europe, 1958-1965.

National Programmes.
Basis for Calculating Capital Costs.
Cost Factors.

Financing Nuclear Energy Programmes and Relations Between the State and Industry.

Comparative Study of Atomic Legislation in Europe.

Studies of the Market for Nuclear Equipment.

1. Fuels.
2. Moderators (graphite, heavy water and beryllium).
3. Special Metals.
4. Fuel Elements.
   Reactor Components.
   Fuel Element Handling Equipment.

(European Nuclear Energy Agency, 38 Boulevard Suchet, Paris 16.)

INDUSTRIAL PROSPECTS

factor of 72%. This figure took into account the necessity for complete shutdown for a fuel changeover. On average, each reactor had four burst slugs per year mainly due to leakage in the closure weld of the Magnox can. Sir William looked forward to a considerable improvement in the Calder design when the first of the U.K. civil stations came into operation in 1961. Slides were shown of the four civil fuel element designs.

Replying to questions, Sir William said that although he thought it would eventually be possible to burn plutonium in the civil power stations, all the plutonium produced initially in the U.K. would be required for the Dounreay fast-breeder reactor. He confirmed that the AEA was now studying a heavy-water moderated, steam-cooled reactor using slightly enriched uranium with pressure tubes instead of a pressure vessel. As yet it had not been decided to build a prototype.

After lunch on the first day, Professor Dr. O. Löbl of the Technischen Hochschule of Aachen presented a detailed analysis of the costs of installing and operating various types of nuclear plant compared with a coal-fired station. The analysis—which had been prepared for RWE, the German electricity supply company—covered light water cooled and moderated, gas cooled graphite moderated and organic moderated.

On the basis of fixed costs Prof. Löbl showed that the gas-cooled system was the most expensive and coal firing the cheapest. He went on to show the economic effect of different fuel cycles on these stations, and spoke of the difficulty of obtaining reliable burn-up figures. In spite of the theoretical claims made for Shippingport which were generally better than 10,000 MWd/t, the average figure so far was only 5,200 MWd/t at an enrichment of 1.76%. At Calder Hall, where the optimum was said to be 3,000 MWd/t a figure of just over 1,000 MWd/t had been achieved, he said. Indeed, more recently there were signs of a retrenchment and the U.K.AEA appeared now to only guarantee 2,500 MWd/t.

The contentions of Professor Dr. O. Löbl, whose cost estimates were all based on "first round" nuclear stations, were to some extent refuted by the next speaker, Mr. Myron C. Beekman, director, nuclear power development dept., Detroit Edison Co. History, he said, has proved that it is difficult, if not impossible, to extrapolate more than a few years into the future. He went on to suggest some of the major technical objectives necessary to achieve significant cost reductions:

(1) Elimination of overdesign in systems and components.

(2) Use of less costly materials and methods.

(3) An increase in the size of individual units.

(4) Improvement of thermal efficiencies.

(5) Simplification of systems.

(6) Development of standards and codes more applicable to nuclear engineering.

(7) Reduction of fuel cycle costs by (a) increasing performance of fuel material (b) reducing fabrication and reprocessing charges and (c) developing advanced fuel concepts such as mobile fuel systems.

(8) Reduction of operating and maintenance expenses.

This was followed by a spirited plea from Mr. Stuart Clarkson (Atomic Energy of Canada) for consideration of Canada's natural uranium, heavy water moderated, reactor. As a result of the development work which AECL has already carried out on a 20 MW unit it is confident that a 200 MW CANDU reactor can be built to operate at 6 mill/kWh. This reactor would use uranium oxide pellets sheathed in Zircaloy with a burn-up of the order of 10,000 MWd/t. Price of the fuel would be $30 lb. giving a fuel cost (allowing 20%) of less than 1¼ mill/kWh. Construction costs for a 200 MW power reactor, excluding development charges, were estimated at $60—70 million or $350/kW.

Discussing the position and future prospects of nuclear power, Ing. G. Valerio, chairman of the Società Elettronucleare Italiana, reviewed some of the reasons why nuclear energy was so much more costly than conventional energy. Only countries with a large base load could afford to install a full-scale nuclear station which must be operated at a high load factor to be economic, he said.

Mr. J. R. Cuthbertson (Lazard Bros.) commented that an assumption of high utilization for nuclear power plant or for conventional plant was dangerously unrealistic. Traditional stations often operated at less than 50 to 60% utilization: calculations for both types of station must be based on realistic operating figures.

Mr. Geoffrey F. Kennedy, of Kennedy and Donkin, felt there was great danger in countries rushing to invest large sums of money in nuclear power plant. Some of the bigger reactors envisaged today might suffer from flux instability, coolant leakages or short-life fuel elements. There was a growing need for completely independent supervision of prospective stations.

The financing of nuclear power programmes was examined in detail during Tuesday's sessions. The first meeting began with a report by Dr. E. Pohland, chairman of the interim board of directors of Eurochemic, on the development of this first joint undertaking for pooling human and technical resources in Europe for the construction of a nuclear fuel reprocessing plant. Emphasizing that participation in the company was open to private as well as governmental organizations, Dr. Pohland pointed out that France, Belgium and Italy had already announced plans for transferring part of their share to private industry.

Mr. Corbin Allardice, adviser on atomic energy to the World Bank, described the Bank's approach to financing nuclear power undertakings with particular reference to the S.E.N.N. (Società Elettronucleare Nazionale) project for the building of a nuclear power station on the Garigliano river, north of Naples. Mr. Allardice stressed that the Bank had no responsibility for the final choice by S.E.N.N. and the Italian authorities of the successful tender for this station, "and that the choice could easily have gone another way." He felt that one of the most significant outcomes of this exercise was that "in the highly competitive field of nuclear power development, the study of the project had been accepted by commercial firms as well as government authorities as a balanced and impartial work and as a valuable contribution to nuclear power development."

Prof. Ing. Felice Ippolito, secretary-general of the Comitato Nazionale per le Ricerche Nucleari (CNRN) in emphasizing the internationally co-operative and impartial nature of the examination of tenders for the S.E.N.N. project, pointed out that the USAEC's Argonne National Laboratory had been asked to provide a technical analysis of the four enriched uranium offers, and the U.K. Atomic Energy Authority Industrial Group at Risley had performed a similar service in regard to the five natural uranium offers. He stressed that the major differences in costs lay not between the enriched and natural uranium systems but between different types of reactor within these two systems. "The solution of many of the problems of underdeveloped areas or areas in process of industrialization, such as Southern Italy," concluded Prof. Ippolito, "lay in the possibility of providing larger quantities of energy at prices lower than the present ones. The Garigliano project marked an important step in this direction."

Dr. Federico Consolo of Euratom spoke on the financial aspects of the recent agreement between Euratom and

the United States. This agreement provides for two programmes of co-operation, an industrial programme for constructing power reactors, and a programme of research and development. Dr. Consolo said that a most promising start had been made in the research part of the programme, which had not received as much attention as the power programme. By April 10 this year private American industry had submitted 43 proposals for research contracts totalling over $20 million. In the six Euratom countries over 120 proposals from 40 industrial firms, the French and Belgian Nuclear Research Centres, Universities, and other research institutes were being considered.

On the basis of the Euratom-U.S.A. agreement, six or eight nuclear power stations were to be built in Europe, with an average capacity of 150 MW. They would be built by public and private concerns within the Community. Construction of the reactors, excluding fuel, was expected to cost about 350 dollars per kW, compared with about 150 dollars per kW for conventional power stations. The total cost of the Euratom building programme would be about $350 million. The agreement with the U.S. provided for supply to the Community of 30,000 kg of uranium 235.

The session continued in the afternoon with a discussion under the chairmanship of M. M. Masoin, president of the Belgian Groupement Professionnel de l'Industrie Nucléaire. Members of the panel were Prof. Ing. A. M. Angelini, vice-president of the Comitato Nazionale per le Ricerche Nucleari (CNRN), Dr. K. Dohrn, director of the Kreditanstalt für Wiederaufbau, Mr. D. E. H. Peirson, secretary of U.K.AEA, Dr. Chauncey Starr, general manager of Atomics International, and M. M. Pascal of the French Atomic Energy Commission.

Contrasting the different approaches to nuclear development of the U.K. and the U.S.A., Mr. Peirson said that whilst the U.K. preferred to work on a narrow front the U.S. had a very widely based programme. "Is there not a danger that too many reactor systems may be set in hand and that progress may therefore be slower?" he asked. Replying for the U.S., Dr. Chauncey Starr commented that the cost of reactor studies or experimental projects was comparatively small in relation to the information they gave.

Summing up, the chairman of this session, M. M. Masoin, mentioned the various methods of financing nuclear energy. Initially, in the U.K. and France there was a strong state support. Now the state was establishing closer contact with private industry. In Italy there was a measure of state support and even in the U.S. there was the idea of systemizing nuclear installations by positive control. In other countries, such as Germany, where private industry was accepting more of the responsibility, there was a tendency for the industry to look to the state for a grant to cover any possible difference in the cost of nuclear and conventional power. Finally, there was the example of countries like Switzerland where private industry was carrying the burden of development with probable assistance from the Government taking the form of an interest-free loan.

Uranium Reserves

In parallel with the sessions on financing nuclear programmes the first of six sessions on marketing opened with a paper by M. J. van der Spek, managing director of Belgonucleaire, who surveyed the world's uranium supplies. He said that present estimates put reserves of uranium oxide which could be exploited economically at 1 million tons. Referring to one of the special studies dealing with the expected nuclear energy production in Europe during the next six years, M. J. van der Spek declared that there should be no difficulty in obtaining an adequate supply of fuel; indeed, the supply could be increased. He added that the price of uranium oxide now seemed to be stabilizing at about $8 a pound. The uranium market, hitherto almost entirely the concern of governments and official bodies, was now becoming more and more a matter for commerce. There were no serious short-term problems; production was adequate to meet demand, the geographical distribution of the uranium mines prevented the formation of monopolies controlling supply, and the various controls established by national governments were not hindering development. In the discussion following this paper several speakers, notably from Canada and the U.K., confirmed M. J. van der Spek's conclusions.

Three speakers contributed to a stimulating discussion on the economics of fuel cycles. Mr. J. Howieson, of Atomic Energy of Canada, drew attention to the extremely attractive natural uranium fuel cycle of the 200 MW CANDU project. The system envisages bi-directional push-through fuelling, the fuel being UO_2 carried in Zircalloy 2 in the form of bundles.

M. J. Andriot, of the Commisariat a' l'Energie Atomique, chose to show how various factors could influence the economy of the fuel cycles for three different types of reactor. The factors he mentioned in this context were interest payable on the cost of the elements, the length of time they were in the reactor, cost of fabrication of various types of fuel, the possibility of a credit for plutonium after reprocessing charges had been met and the overall influence of the capital cost of the reactor.

The third speaker, Mr. R. L. Witzke, engineering director of Westinghouse International Atomic Power Co., produced tables of statistics and gave the costs of a complete fuel cycle for a 600 MW water-moderated unit burning enriched uranium. Fuel costs were given for a range of burn-ups from 12,000 to 20,000 MW per 1,000 kg. Fuel costs were 4.08 mill/kWh and 3 mill/kWh respectively.

Contributing to the discussion, Mr. W. R. Wootton, director of the atomic energy department of Babcock and Wilcox, commented that the fuel cost for the 500 MW Hinkley Point station would be 3.3 mill/kWh. Overall power cost would be 8 mill/kWh. He agreed that this figure had been partly achieved by the comparatively low rates of interest in the U.K. but added that another reason was the economy of building two reactors simultaneously.

Dr. Chauncey Starr, general manager of Atomics International, produced a graph showing approximate burn-up figures for three fuels, natural uranium, UMo and UO. He expressed the opinion that the two last mentioned had intriguing possibilities which had been partially confirmed by irradiation experiments. "We need many more statistics on burn-up figures," he concluded.

The session continued with an outline of the special characteristics required of nuclear equipment and their influence on traditional manufacturing processes. Mr. W. R. Wootton impressed all delegates with a forthright declaration, obviously based on experience, that because of the stringent conditions called for, only the larger boilermakers dare engage in nuclear manufacture. Mr. J. M. Hill, of the U.K.AEA, also referred to the complexity of fuel element manufacture. The choice of the canning material, which might be based initially on grounds of its suitability was also dependent on the development of economic methods of production. As an example he cited some of the arguments in favour of stainless steel or beryllium as a carrying material for the AGR enriched uranium elements.

Reducing Costs

The panel discussion in the afternoon under the chairmanship of Mr. John Menke, president of the Nuclear Development Corp. of America, hinged on probable factors reducing production costs of reactor components. Several speakers suggested that manufacture in Europe would automatically lead to a reduction in costs because of lower labour costs. Mr. E. Demierbe felt that when the European programme was in full swing. the industry's greater technical experience would lead to simplification, wider tolerances and a more reasonable interpretation of safety standards. A most useful contribution was made by Dr. L. Kowarski of O.E.E.C. Taking the British programme as an example he showed how economy of technical effort and finance could be effected by working on a narrow front. The impressive feature of the British gas-cooled graphite moderated reactors was the way in which the development of Calder Hall had led naturally to the civil power programme. The next stage, the AGR, would see a proportionate lowering of costs as a result of the practical experience gained with the earlier reactors.

Mr. R. D. Vaughan, director and chief engineer, N.P.P.C., thought that there was still plenty of room for improvement in the British civil reactors especially so far

as heat transfer was concerned. He suggested there was an interesting possibility of making larger reactors with a multiplicity of small heat exchangers.

The afternoon session, under the chairmanship of M. Fleury, was devoted to markets for the special metals which are used in nuclear reactors, and to possible markets for these metals outside the nuclear field.

Dr. A. Boettcher, director of Degussa, explained that, for nuclear purposes, the various metals concerned had to be made by special processes because of the extremely high quality demanded. This set many special and difficult problems for industry, and resulted in the materials being extremely expensive: for example, beryllium, which was required in quantities of the order of hundreds of kilos, cost at present about $670 per kilogram, a price similar to that of gold.

Prof. Dr. H. Hohn, director of the Osterreichische Stickstoffwerke A.G. (Austria), gave a paper on the uses of special nuclear material outside the nuclear field. He explained that the developments in production methods which the nuclear industry had demanded had resulted in materials becoming available for other purposes which could not have been developed economically for these purposes alone.

Atomic Law

Two important sessions were devoted to the legal problems set by the increasingly rapid development of nuclear power in the countries of Europe.

The first session, under the chairmanship of Professor Felice Ippolito, of Italy, began with papers by Prof. B. Gomard, legal adviser to the Danish Atomic Energy Commission, and Prof. O. Kaufmann, of the University of St. Gall.

Prof. Gomard described the various reasons which had led to the creation in many countries of new forms of administration in the field of nuclear industry, that is to say either Commissions or semi-public bodies, able to combine the activities of research and industrial exploitation with the normal activities of State administration. Prof. Kaufmann dealt with the question of State control over nuclear industry, explaining the features of the different systems ranging from the monopoly of a State in nuclear activities to the usual police control of dangerous activities. Both speakers dealt with the "political philosophy" of the nuclear industry.

The particular form of State intervention in the nuclear industry adopted by Euratom was explained by Mr. Th. Vogelaar, director-general of the Euratom legal service. He said that one of the main principles was to speed up the development of a sound nuclear industry in the countries concerned.

Mr. Max Isenberg, special assistant for atomic energy at the U.S. Embassy in Paris, surveyed the development of international security control, the purpose of which was to avoid military use of nuclear projects provided for by International Organizations. He explained the system of the International Atomic Energy Agency whose statute had been signed by more than 80 States all over the world. He stressed that industry should not fear inspection resulting from such a control, because inspection would not mean interference in production procedures. On the contrary, it could help the industry because it would not only cover the field of military diversion but also the field of health protection.

The second legal session was devoted to the problems of information and the protection of inventions in the nuclear field. In a panel discussion presided over by M. de Haas (Netherlands), deputy secretary general of Philips and director of the Reactor Centrum Nederland, representatives of France, the Netherlands, United Kingdom, the United States and Euratom gave a survey of the present legal situation, especially with regard to private industry.

The ensuing discussion showed that all States, public bodies and international bodies like Euratom undertaking research on their own, are under a legal obligation to put results of such research in the field of peaceful applications of nuclear energy at the disposal of their private industry.

A more complex situation, however, was revealed in the field of patents, in particular in those States or territories where a public body undertakes research and may thus acquire patents. Moreover, sometimes the State can obtain, by compulsory means, the use of a private patent. It was pointed out by the representatives of the United States and Euratom that no use of these compulsory powers has yet been made and that probably they will not be used in future.

If the State or a public body owns a patent, different systems of granting licences may be applied. Whilst in the United States the principle of royalty-free licences for private industry is applied, the European countries, and in particular European industry, favour the commercial sale of licences.

The great activity of some States in the field of nuclear energy, and their consequently strong position as owners of patents, give rise to some concern that the financial value of a patent, which can be an important stimulus to industrial progress in private industry, might become weakened. European industry believes that its important contribution to the development of the peaceful uses of nuclear energy should not be discouraged by endangering the financial value of their industrial advances.

Opening a series of discussions on the market for nuclear equipment, Indatom's director general, M. R. Gibrat, commented that one purpose of the meetings was to show the way ahead. "Those who are afraid of what the future holds should drop behind now," he said. "These are the crossroads for those who want to go on." The European market could be organized so that each different item of equipment was made in a separate factory.

Alternatively, because of the large sums of money involved, it might be preferable to launch nuclear programmes progressively from country to country. Whichever method was chosen he was quite sure that it would be necessary to have agreements between companies in different countries to achieve a maximum interchange of information. Stresa might well be the beginning of such activity.

The next speaker, however, Mr. Edgard Demierbe, director of A.C.E.C.'s nuclear division, felt that the real obstacle to a European programme of nuclear manufacture was the lack of technicians. It was important, he said, to implement as soon as possible facilities for training personnel.

Following speakers did not take up this theme. Instead they spoke of the nuclear components that were already being made or which could be made by virtue of existing skills. Belgium for example, has the capacity to make UO_2 fuel elements; France is currently preparing designs of reinforced concrete pressure vessels for higher temperatures.

On the last day the marketing group turned their attention to the nucleonic instruments required. By way of introduction, Dr. Denis Taylor, director of Plessey Nucleonics, presented a breakdown of instrumentation costs—$30,000 for a research reactor, $300,000 for a power reactor and from $1 to 2 million for a complete power station. Quoting from one of the O.E.E.C. studies, he commented that for a Calder Hall station, the control equipment was worth only 4.6% of the total cost.

Dr. Taylor went on to show how the types of instruments required varied between power and research reactors, the comparison being made by means of the following table:—

Class of Instrument	Power Reactors	Research Reactors
Nucleonic	10%	35%
Conventional	20%	20%
B.S.D.	40%	5%
Flux Scanning	13%	—
Actuators (control rod)	11%	25%
Health	6%	15%

These figures covered only the basic types of instruments and Dr. Taylor listed a further eight groups that might be incorporated in a reactor.

The group subsequently discussed the differing instrument requirements of various types of reactor. One speaker mentioned the attractive possibilities of an automatic sequential scanning unit obtaining information in digit form and presenting it to the operator by means of, say, an automatic typewriter.

A notable contribution to the proceedings was made by Mr. P. Hjertberg, of A.S.E.A., Sweden, who, in a short contribution, showed that there was plenty of room for improvement in the design of instruments for reactor applications. He felt, for example, that resistance thermometers used with sensing elements having short time constants and a high degree of resistance to radiation might replace thermocouples.

NEW BOOKS

Elsevier's Dictionary of Nuclear Science and Technology. (English/American, French, Spanish, Italian, Dutch and German.) Compiled by W. E. Clason. Elsevier Publishing Co., Amsterdam. (1958.) (Distributor for the British Commonwealth excluding Canada: D. van Nostrand Co., Ltd., London, W.14.) 140s.

This is the 4th volume in a series of multilingual dictionaries published by Elsevier and should prove a good investment for those working in atomic energy, obliged to read or write in more than one of the leading languages. The dictionary lists 4,000 terms, arranged in alphabetical order of the English expressions. Care is taken to distinguish clearly between American and British usage and to co-ordinate such terms as "Trace Chemistry" and "Microchemistry," for instance. A 1-3 line definition is added in each case.

A special feature of the book is its handy format and lay-out, which greatly facilitates speed in consulting the dictionary. The major part consists of the so-called Basic Table, where the English expressions and definitions are printed on the left-hand page and the corresponding expressions in the five other languages on the right-hand page, on the same horizontal line. In addition to the Basic Table, there are five properly cross-referenced Glossaries, each representing an alphabetical index of the terms in French, Spanish, Italian, Dutch and German, respectively.

Introduction to Neutron Physics. By L. F. Curtiss. (580 pp. D. van Nostrand Co., 1959.) 73s.

The history of the realization of the neutron is instructive. After the now historic Bakerian Lecture in 1920, in which Rutherford collected the neutron prophecies, there was no appreciable advance until Chadwick resolved the problem and gave the mass of the neutron within 0.2%, after a number of eminent experimenters had been handling the "missing link" for a year, but thinking that it ought to be something else. The most spectacular effect produced by neutrons is the nuclear fission by chain-reaction, leading to A-bombs, experimental and power-producing reactors, the latter being established and forming the basis of the present ambitious power programme for this and other countries, as well as for ship-propulsion, already achieved in submarines and soon, it is hoped, in ice-breakers.

The separate chapters, after an extensive Introduction, deal respectively with Interactions, Sources, Detectors, Spectrometers and Monochromators, Interaction with Matter, Calibrations and Standards, Neutron Shielding and Protection for Personnel, the last explaining in detail the consequences of irradiation. Each chapter terminates with a list of symbols, a set of stiff examples for practice in computation, and an ample bibliography. The Appendix collects useful formulæ and data associated with the subject, particularly accurate atomic-mass tables.

The author is concerned throughout with the fundamental aspects of neutrons for all these basic and applied purposes, and the range of his treatment indicates that, within a generation, the study of neutrons has grown into a life-long vocation. From the engineering point of view, the formal exposition of the properties of neutrons, which make possible the various types of reactor, is most welcome and readable. This will remain a source-book for many years, in spite of the present rapid progress in this field.

L.E.C.H.

The Physical Theory of Neutron Chain Reactors. By A. M. Weinberg and E. P. Wigner. (800 pp.) The University of Chicago Press, 1958. (Agents: Cambridge University Press, Bentley House, 200 Euston Road, London, N.W.1.) 112s. 6d.

The authors of this book are distinguished nuclear scientists, who have been engaged in nuclear reactor research and design since the subject's earliest days. Their book is an authoritative account of the most accurate knowledge at present available.

The subject matter of the book divides into four sections. These are nuclear physics of neutron chain reactions, neutron transport theory, homogeneous reactor theory and heterogeneous reactor theory.

The physical principles of these subjects are discussed carefully and at length; approximations valid in some circumstances are described clearly and critically. Formulation of basic equations from appropriate physical laws and explicitly stated assumptions is considered much more important than the mathematical details of the solution of the equations. Wherever relevant experimental information is available, it is compared with theoretical predictions.

This approach produces a more sophisticated account of nuclear physics than is generally provided for the reactor physicist. Indeed, the whole text shows careful attention to detail. The theory of fast and intermediate reactors (as an application of homogeneous reactor theory) is discussed more extensively than in previous works. The authors appear sensitive to a possible charge of failing to give adequate information on the computing machine techniques now becoming popular. This topic is unrelated to considerations of physical theory, and its absence appears justified.

The book is therefore not an engineer's manual, nor a handbook of mathematical formulæ, but a scholarly, definitive statement of the present state of relevant physical knowledge. It should become standard reading for all engaged on reactor physics research, design or development.

P.H.P.

Books Received

Radiations and Matter. By A. Berthelot. (English translation by F. R. Paulsen.) 180 pp. Leonard Hill (Books), Ltd.; Eden Street, London, N.W.1. (1958.) 25s.

The New Materials. By G. Leach. (Progress of Science Series: Editor, N. Calder.) 71 pp. Phoenix House, Ltd.; 38 William IV Street, Charing Cross, London. (1958.) 9s. 6d.

Nutzenergie aus Atomkernen. By K. R. Schmidt. Vol. I. 594 pp. Walter de Gruyter and Co.; 13 Genthiner Strasse, Berlin W.35. (1959.) DM.106.

Nuclear Reactors for Power Generation. Edited by E. Openshaw Taylor. 144 pp. George Newnes, Ltd.; Tower House, Southampton Street, London, W.C.2. (1958.) 21s.

Recommendations of the International Commission on Radiological Protection. 18 pp. Published for the International Commission on Radiological Protection by Pergamon Press, Ltd.; 4-5 Fitzroy Square, London, W.1. (1959.) 3s. 6d.

Nuclear Reactions. Edited by P. M. Endt and M. Demeur. Vol. I. 502 pp. North-Holland Publishing Co.; P.O. Box 103, Amsterdam. (1959.) 86s.

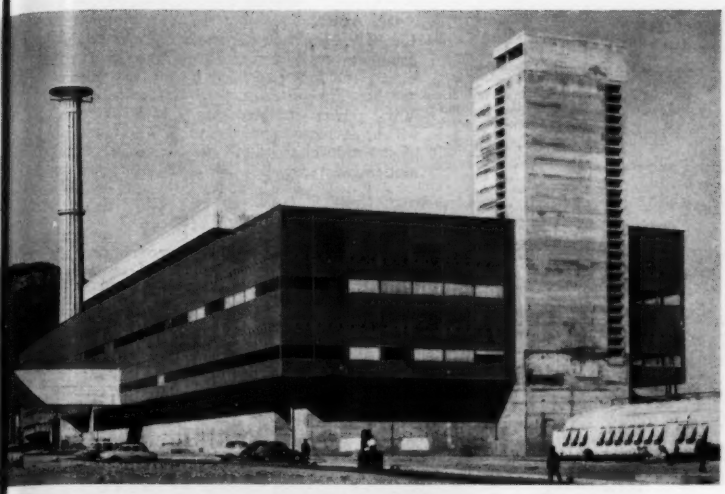
Materials for Nuclear Reactors. Edited by B. Kopelman. 411 pp. McGraw-Hill Publishing Co., Ltd.; 95 Farringdon Street, London, E.C.4. (1959.) 93s.

Non-destructive Testing. By J. F. Hinsley. 495 pp. MacDonald and Evans, Ltd.; 8 John Street, London, W.C.1. (1959.) 75s.

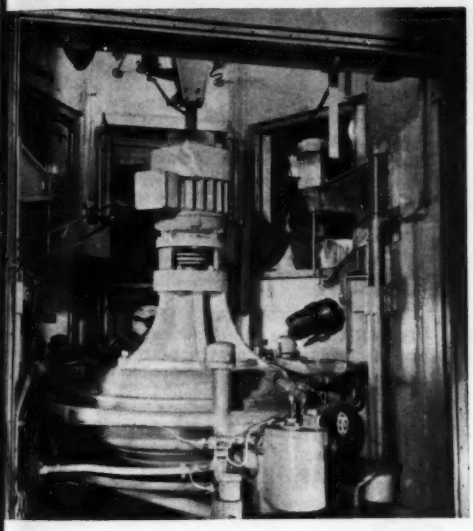
Fundamental Aspects of Reactor Shielding. By H. Goldstein. 416 pp. Addison-Wesley Publishing Co.; 10-15 Chitty Street, London, W.1. (1959.) 72s.

Physics and Heat Technology of Reactors. Supplement No. 1 of the Soviet Journal of Atomic Energy. Translated and published by Consultants Bureau, Inc., New York. 174 pp. Distributors in the British Empire: Chapman and Hall, Ltd.; 37 Essex Street, London, W.C.2. (1958.) 168s.

Analysis of Pipe Structures for Flexibility. By J. Gascoyne. 181 pp. Sir Isaac Pitman and Sons, Ltd.; Pitman House, Parker Street, London, W.C.2. (1959.) 45s.



The first plutonium extraction plant in continental Europe located at Marcoule, France, where the G2 reactor has recently been connected to the grid making the station the first nuclear power producer for industrial purposes in Europe.



A stage in plutonium production at Marcoule. In the final treatment of the plutonium oxalate, before metallurgy, the liquid is centrifuged in a gas-tight cell.

World News

International

DECISIONS by the Board of Governors of the IAEA include proposals to set up isotope training centres in Arab, African and Middle East countries; to send technicians to Burma, Greece and the United Arab Republic and the supply of some equipment to the two former countries, and to send preliminary assistance missions to several Far Eastern and Latin American countries. This is in addition to the nuclear power survey team which is to visit the Argentine and Brazil.

AN OFFER of $600,000 has been accepted by the IAEA from the U.S.A. towards the construction of the functional laboratory to be built at Seibersdorf, near Vienna. The Netherlands are to supply a gamma spectometer for the laboratory.

GENERAL FUND of the IAEA is now more than $1 million. Recent pledges made by member states are: U.S.S.R. $125,000; Australia, $10,000; South Africa, $10,000 and Finland, $5,000.

THE SECOND preliminary assistance mission of the IAEA has left Vienna for a tour of Formosa, Japan, Korea, Viet-nam and the Philippines to carry out a survey to determine the most effective means of instituting nuclear energy programmes. The first mission surveyed Burma, Ceylon, Indonesia and Thailand.

URANIUM FIGURES for the non-communist world are estimated to be:

	Production tons	Reserve tons
Canada ..	13,537	413,000
U.S.A. ..	12,560	221,000
South Africa	6,245	330,000
Belgian Congo	1,000	10,000
France ..	815	50,000
Australia ..	700	15,000

THE FIRST Chemical Institute of the University of Vienna will be aided by the IAEA in obtaining irradiated uranium oxide from the Institute of Nuclear Physics in Prague. The material, which is being supplied free of charge, will be transmitted to the IAEA and then passed on to the Austrian Institute.

United Kingdom

IN REPLY to Opposition calls for an amendment to the Nuclear Installations (Licensing and Insurance) Bill, the Government has stated that it does not propose to exclude industry from fuel element manufacture nor reactor operation.

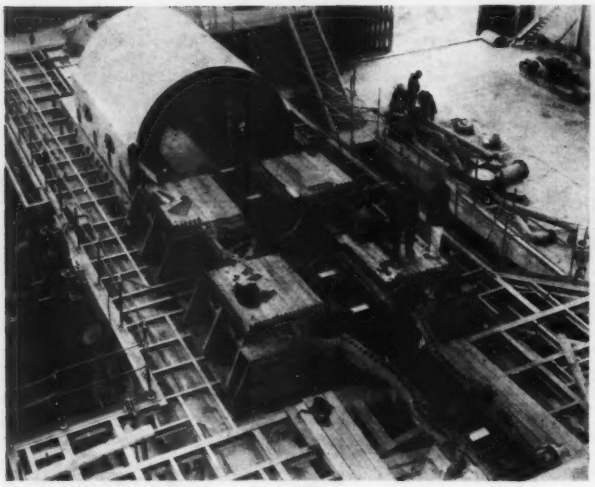
THE QUESTION raised in Parliament as to whether it is possible that ships to replace the "*Queen Mary*" and "*Queen Elizabeth*" could have nuclear propulsion, has received a discouraging reply.

DREADNOUGHT'S keel will be laid by the Duke of Edinburgh at the Vickers-Armstrongs yard at Barrow-in-Furness on June 12. Admiral of the Fleet, Lord Mountbatten, disclosed recently that the keel will consist of a large hoop of steel which will be the central section of the boat.

THE AEA are to stage a nuclear energy exhibition at Stromness, Orkney, this summer in conjunction with the Stromness Chamber of Commerce. The exhibition will illustrate the part nuclear power will play in the development of the area.

GLASGOW CORPORATION are considering the setting up of a monitoring service to detect radioactivity in air, water, milk and sewage of the city.

NORTH OF SCOTLAND Hydro-Electric Board are still examining the possibility of erecting a nuclear power plant but no site has been decided upon yet.



Assembling No. 1 main turbine alternator at the Bradwell nuclear power station being built by Nuclear Power Plant.

Australia

RESEARCH GRANTS totalling nearly £A28,000 have been awarded by the Atomic Energy Commission to seven universities for work in fields which would contribute to the Commission's work in developing industrial uses of nuclear energy.

DURING HIS VISIT to Australia, Sir Leonard Owen, managing director, Industrial group, U.K. AEA, visited several Atomic Energy Commission establishments and the Mary Kathleen uranium mine. He also presented a paper, "Engineering prospects of the U.K. nuclear power programme," to the Sydney and Melbourne divisions of the Australian Institution of Engineers.

Canada

$600,000 CONTRACT has been awarded by Atomic Energy of Canada to Canadian General Electric for the design, study and development of a nuclear power station suitable for use in the Arctic.

URANIUM DELIVERIES by Eldorado Mining and Refining, for the first quarter of 1959, amounted to 3,881 tons, valued at about $79 million, this is one-third higher than the amount delivered during the same period last year.

EXPLODING ATOMIC BOMBS in the Athabasca tar sands next year may be successful enough to start an entirely new industry, Director of the Canadian Department of Mines and Technical Surveys, Dr. J. Convey, has told the House of Commons Mines Committee. The tar sands which contain about 300,000 million barrels of oil, almost double the world's known reserves, are expected to yield 10,000 barrels of oil from the initial blast, which will be carried out by Richfield Oil of Los Angeles. The explosion is expected to create a subterranean cavity into which oil that has been separated from the sand by the heat will gather.

THE PRIME MINISTER, Mr. Diefenbaker, has assured the House of Commons that steps will be taken towards forming another uranium sales contract with the U.S.A. before the existing one expires in 1962. 413,000 tons of uranium are reported to be the reserve total for the country.

Ceylon

THE ATOMIC ENERGY Committee of the National Planning Council, has recommended to the Government that a Central Atomic Energy Authority should be set up immediately to cover all aspects of nuclear development in the country. Also that a comprehensive survey of radioactive mineral resources be made and regulations set out for the storing and handling of radioactive material.

France

AN AGREEMENT has been signed with the U.S.A. for the supply of enriched uranium to fuel the nuclear submarine now under construction at Cherbourg. It provides for the sale of 970 lb of enriched uranium over the next 10 years.

ON APRIL 23, one of the reactors of the 130 MW Marcoule G2 nuclear power establishment, was connected to the grid to supply the first electricity by nuclear power to western continental Europe. The initial power obtained was 9 MW but this will be increased progressively. The plant is of the natural uranium, gas-cooled, graphite moderated type.

West Germany

PILOT PLANT for the production of heavy water using the H_2S dual temperature process is to be erected by Pintsch Bamag following the placing of an order by the Federal Ministry of Atomic Energy. The plant is expected to be completed early 1960.

Indonesia

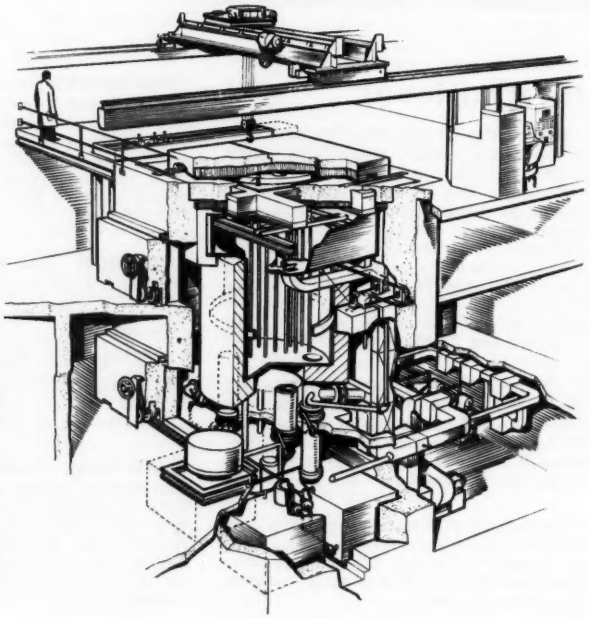
AN INSTITUTE of Atomic Energy, under the direct supervision of the Prime Minister, is being formed to regulate and supervise all nuclear energy matters. In addition, work on a nuclear programme is being carried out at Bandung, Bogor, Djakarta and Jogjakarta.

Italy

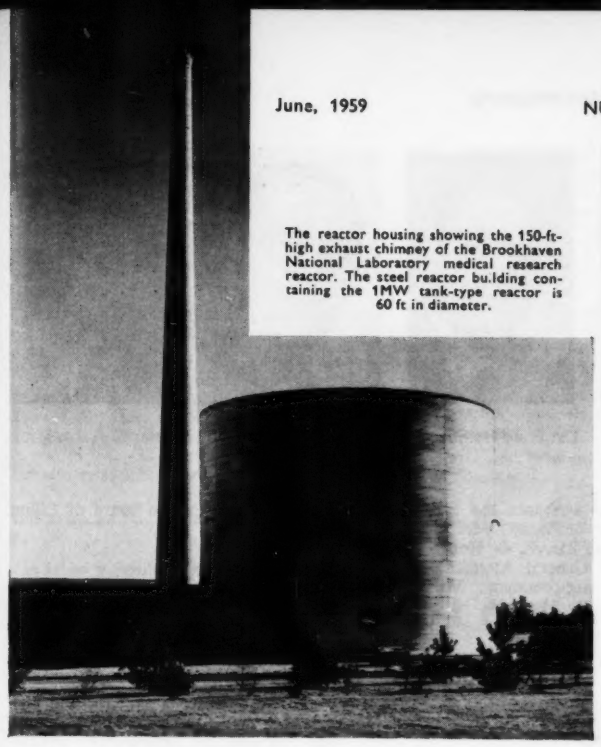
AN ALLOCATION of $350,000 towards the cost of a research reactor, has been made by the U.S.A. The sum will help pay for the $4 million 5 MW, heavy water tank-type research reactor recently inaugurated at Ispra.

Japan

TWO ELECTRICAL MANUFACTURERS, Toshiba and Hitachi, are reported to have submitted plans for experimental and training reactors to the Atomic Energy Bureau with the view to qualifying for subsidies for the domestic production of experimental reactors.



The low-power reactor ZED-2, for testing nuclear power fuel rod arrangement which is to be built for Atomic Energy of Canada at Chalk River by Foster Wheeler. The reactor will have a 100 W power output and will be heavy-water moderated with bundles of uranium oxide rods being used in the early experiments.



The reactor housing showing the 150-ft-high exhaust chimney of the Brookhaven National Laboratory medical research reactor. The steel reactor building containing the 1MW tank-type reactor is 60 ft in diameter.

Japan (contd.)

THE TOKYO International Trade Fair has a large section devoted to nuclear engineering. It includes a U.S. exhibit of a working reactor used for training physicists and a 40-ft full-scale model of the pressure vessel and core of the Shippingport power reactor.

Mexico

RESERVES of radio-active minerals are reported to be thus: Eight thousand tons in the Sierra de Gomez, State of Chihuahua; one million tons of mixed copper and uranium, estimated to yield 2,000 tons of uranium, near Tonichi, and important resources near Ojinaga, Nacozan, Vizanon and in the State of Oaxaca.

Norway

THE HEAD of the water reactors section of the Argonne reactor engineering division, Argonne National Laboratory, U.S.A., Mr. L. W. Fromm, has joined the staff at Halden to investigate the performance of the HBWR components and materials. He will also assist in specifying materials for the second reactor core.

Puerto Rico

THE FIRST REACTOR for Central America has been shipped to Mayaguez, Puerto Rico. The reactor is a 10 W solution-type, built by Atomics International for the Puerto Rican Nuclear Centre for research and study purposes. It is eight feet high by eight feet in diameter and can be installed in a laboratory or industrial plant without additional facilities.

Spain

NUCLEAR MATERIALS will be shown among the British exhibits at the Barcelona Samples Fair to be held from June 1-20.

South Africa

THE GOVERNMENT have informed the IAEA that they are prepared to sell uranium oxide to the Agency at $8/lb. The oxide would be supplied as a calcined concentrate and 1,000 tons per year is available at relatively short notice.

U.S.S.R.

TASHKENT INSTITUTE of Nuclear Physics is soon to have a reactor, a cyclotron and several other accelerators in operation.

A NEW REACTOR is being built for the Latvian Academy of Sciences, near Salapils in Latvia, with the help of several Soviet scientific institutions. It will be completed early next year and will be used mainly in the investigation of isotopes for industrial uses.

A CYCLIC ACCELERATOR with spatial magnetic field variation has been developed by the Joint Nuclear Research Institute at Dubna, near Moscow. It is a new type of charged particle accelerator.

A NEW SECTION of the Georgian Academy of Sciences will be opened shortly for the elementary study of particles and their structure. It will have a reactor for studying the interaction of neutrons and atomic nuclei.

SIX NUCLEAR SCIENTISTS recently visited the United Kingdom where they inspected several establishments of the U.K. AEA. The delegation was led by Professor B. Kanstantenov of Leningrad.

U.S.A.

TRITIUM GAS, for civilian use, has been made available by the AEC. Chairman, Mr. John McCone, has announced that 1,000,000 curies are available and that additional amounts on a continuing basis, until private sources become available, will be supplied.

THE FIRST nuclear powered merchant ship, *Savannah*, to be launched on July 21 at Camden, New Jersey, will be christened by Mrs. Dwight D. Eisenhower. The engineering crew of the ship are at present receiving instruction in reactor theory and operation at the U.S. Maritime Reactor School in Lynchburg.

THREE STUDIES, dealing with industrial uses of high intensity radiation, have been presented by three AEC contractors as a part of the panel conference on nuclear energy in industry sponsored by the National Industrial Conference at Cleveland. The studies have been conducted for the Commission under contract.

PRELIMINARY REPORTS on radioisotope applications in industry indicate that the petroleum industry enjoys the most benefit from applications of radioisotopes. This industry is followed closely by the chemical and allied products industry. Major benefits have also been reported by the tobacco, rubber, paper and paper products industries.

A TWO-DAY SYMPOSIUM on industrial uses for radioisotopes was held at Atlanta, Georgia, in May, by the Georgia Institute of Technology in conjunction with Lockheed Aircraft.

NEGOTIATIONS have been authorized by the AEC with Kaiser Engineers, Oakland, California, for the main work in the $145,000,000, graphite-moderated reactor to be built at the Hanford Works, Richmond, Washington. The reactor is for the production of special nuclear materials, with design features capable of conversion to direct power production. Sixteen firms were originally invited to submit proposals.

REGULATORY AMENDMENTS, setting lower limits on radiation exposures, have been approved for publication by the AEC. This will put into effect, for Commission licensees, the latest recommendations of the National Committee on Radiation Protection and Measurements concerning maximum permissible accumulated radiation exposures.

A SERIES of co-ordinated meetings will be held by the American Nuclear Society in conjunction with the Atomic Industrial Forum. The meetings have been planned to bring into focus the latest developments in technical and business spheres of the commercial uses of nuclear power.

A CONTRACT to design and engineer a $3,500,000 pilot plant for reprocessing power reactor fuels has been awarded to Vitro Engineering. The plant will be constructed at the Oak Ridge National Laboratory in Tennessee. The new plant will combine existing chemical reprocessing pilot plants with new head-end cells to permit the dissolution and feed preparation of spent power reactor fuel elements.

A TWO-DAY MEETING on the theoretical aspects of controlled fusion research was held recently at the Oak Ridge National Laboratories.

THE SECOND SERIES of specialized courses in reactor technology for scientists from the U.S. and abroad will be held at the Oak Ridge National Laboratories, starting November 2. The first course, which began in February, is still in operation.

Personal

Dr. C. R. Tottle.

Dr. F. de Hoffmann.

Mr. C. H. Norton.

Mr. R. A. Senior.

Appointments

Dr. C. R. Tottle, formerly deputy director and head of the reactor division at Dounreay, as Professor of Metallurgy and director of the metallurgical laboratories of Victoria University, Manchester.

Mr. W. P. Warren, formerly commercial manager, Industrial Group of the AEA, as sales director of Cambrian Wagon and Engineering, a subsidiary of the Powell Duffryn Group.

The Earl of Halsbury to the board of Head Wrightson Processes.

Mr. G. W. Grossmith as chairman and **Lt.-Col. E. Ward** as managing director of Strachan and Henshaw.

Mr. R. A. Senior as director and manager of John Thompson Instruments.

Mr. P. T. Thornhill as assistant chief engineer (contracts), switchgear dept., and **Mr. H. Walker** as assistant manager, staff recruitment and training of Metropolitan-Vickers.

Mr. A. A. Morris as sales manager of Northey Rotary Compressors.

Atomic Power Constructions announce the following appointments: **Mr. H. E. Dixon,** as head of research and development; **Dr. A. G. H. Coombs,** as deputy head of laboratories and **Mr. D. C. F. Lunn** as chief metallurgist.

Mr. M. E. Peplow as regional research and development officer for southern, south western and south Wales region, CEGB.

Mr. S. A. Hiscock has joined the Lead Development Association.

Electrical Development Association appointments are: **Sir Josiah Eccles,** president; **Mr. A. W. Ferguson** and **Mr. J. Mould,** vice-presidents; **Mr. T. E. Daniel** chairman of the Council and **Mr. D. B. Irving,** vice-chairman.

Mr. C. Robinson.

Mr. J. R. Wetch.

General Dynamics announce the following: **Mr. F. Pace** as chairman; **Mr. E. D. Johnson** as president; **Dr. F. de Hoffmann** as president of the General Atomic Division and a senior vice-president; **Mr. C. Shugg** and **Mr. C. R. MacBride** as vice-presidents.

Mr. C. H. Norton as commercial manager of Semiconductors.

Mr. W. Hackett and **Mr. R. D. Young** as assistant managing directors of Tube Investments.

Col. A. E. Tyler as managing director of W.S. Electronics (Production).

Mr. G. C. D'Arcy Biss as an additional director of the Fairey Company.

Mr. J. C. Haselgrove to the board of United Wire Works (Birmingham) and sales organizer.

Mr. P. Ainley and **Mr. A. E. Palmer** to the board of George Wimpey.

Mr. A. H. Hird to the board of English Steel Corporation.

Lord Rothschild to the board of Shell Research as a part-time adviser on research.

Mr. F. T. Blakey as business manager and a special director of Bristol Siddeley Engines.

Hawker Aircraft announce the following: **Mr. J. T. Lidbury** as managing director; **Mr. R. H. Chaplin** as executive director and chief designer; **Mr. E. G. Rubython** as executive director; **Sir Sydney Camm** as chief engineer; **Mr. J. A. R. Kay** and **Mr. S. D. Davies** to the board.

Mr. G. S. Stevens as vice-chairman; **Mr. H. C. Wilson Bennetts** as joint managing director; **Mr. G. F. Williams** and **Mr. C. W. Ferguson** to the board of Allied Ironfounders.

Mr. D. M. Boyd as chairman of the Association of Chemical and Allied Employers.

Mr. R. Chiles as chairman of Longclose Engineering.

Mr. E. Blankenmeister as district manager (Chicago and Mid-West) of Tracerlab.

Mr. J. R. Wetch of Atomics International to the research advisory committee of the National Aeronautics and Space Administration.

Mr. C. Robinson as branch manager of the new Newcastle field office of Square D.

Mr. R. S. Hewitt to the board of Elliott Brothers (London).

Mr. F. W. Drosten as director of Metallurgical Development for Heavy Minerals.

Mr. H. A. Quinn as director of industrial security for American Machine and Foundry, Government Products Group.

Mr. L. Olorenshaw as member of the parent board of Taylor Woodrow.

Lord Ebbisham has been re-elected president of the London Chamber of Commerce.

Mr. A. N. Bicket and **Mr. J. K. Howarth** to the board of Barrow Haematite Steel.

Mr. T. A. Stone as special assistant to the president of International Nickel.

Mr. E. T. Wilkinson as southern area sales manager for Rocol.

Mr. A. G. Matthews as work study engineer of Quickfit and Quartz.

Rear Admiral K. R. Buckley as director of engineering and electrical training and Chief Naval Electrical Officer, Admiralty.

Dr. W. Steven, superintendent of the development and research laboratory of Mond Nickel, as Director of Research, development and research division of International Nickel. **Dr. G. L. J. Bailey** will take his place and **Dr. W. Betteridge** has been made superintendent of the platinum metals research laboratory.

Mr. F. K. Trask and **Mr. H. A. Kroeger** to the board of Vitro Corporation.

Mr. G. D. Ball as manager of the new Southampton offices of Ransome and Marles.

Mr. H. W. Fender, of Prodorite, has been re-elected as chairman of the British Chemical Plant Manufacturers Association.

Recent Atomics International appointments are: **Mr. H. M. Gilroy,** in-pile irradiation of organics; **Mr. M. A. Perlow,** heat transfer and fouling; **Mr. K. H. Campbell,** OMRE fuel change and coolant clean equipment; **Mr. B. L. Hoffman,** analysis and engineering of advanced OMR concepts.

Sir George Briggs as part-time member of London Electricity Board.

Mr. H. T. Hill to the board and general manager of Wellworthy.

Personal—contd.

Mr. J. Bent as sales engineer of Rosite.

Mr. D. W. Malim as project engineer of the Metal Industries Group.

Obituary

Nuclear Engineering regrets to report the deaths of the following:—

Mr. A. P. Chalkley, editorial director of Temple Press Limited, on April 19 at the age of 73. Mr. Chalkley was founder editor of *The Motor Ship*, editor of *The Motor Boat and Yachting* from 1912 to 1955, and founder editor of *The Oil Engine and Gas Turbine*, remaining as editor until 1945.

Mr. R. Aves, chief experimental officer, reactor division, Harwell, on May 8, at the age of 50. In 1956 Mr. Aves won an Individual Merit promotion to chief experimental officer.

Retirements

Mr. K. J. Cook, chief mechanical and electrical engineer, Eastern and North Eastern regions, CEGB.

Mr. S. Bates, secretary, commercial manager and local director of Consett Iron.

Mr. G. A. Plummer from the board of John Thompson.

Mr. W. B. Spencer, general manager, contractors plant division, Thos. Ward.

Mr. K. R. Hopkirk, formerly director and chief mechanical engineer of British Thomson-Houston.

Tours

Mr. R. Beldam, managing director of Beldam Asbestos, to South Africa.

Mr. J. M. Storey, managing director of Dewrance, to the U.S.A.

Mr. J. E. C. Bailey, chairman and managing director of Baird and Tatlock, to the U.S.A. and Canada.

Industrial Notes

Savage and Parsons are to supply Aktiebolaget Atomenergi, of Sweden, with 12 master slave manipulators for the remote handling of radioactive materials. The order is valued at £15,000. In the past two years 98 of these units have been ordered by countries overseas.

Elliott Brothers (London) have secured the exclusive manufacturing and selling rights in the U.K. of the **Curtiss-Wright** nucleonic thickness-measuring apparatus.

An exhibition by the **CEGB** showing how the future demand for electrical power will be met by nuclear power plants, was held at Stokefield House, Thornbury, Gloucestershire, on May 4-9.

Electro-Hydraulics have established a new industrial hydraulics sales department under the direction of Mr. L. Rumley, the sales director of Electro-Hydraulics and Conveyancer Fork Trucks.

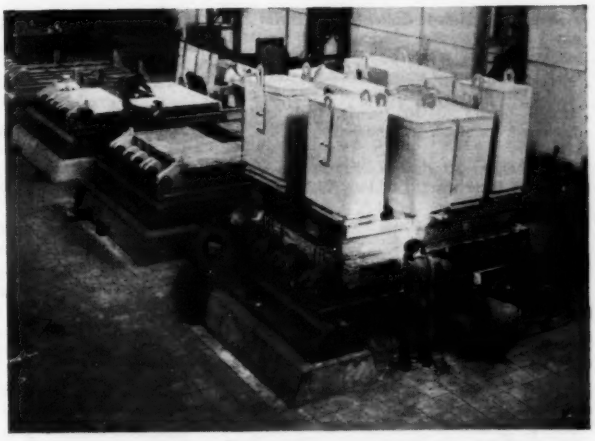
The growing importance of p.v.c. and similar materials in combating corrosion, was made obvious at the **Corrosion Exhibition** held at the Royal Horticultural Society's New Hall, April 27-30. Of special interest were Detel Products, who showed their new Atomicote, a chlorinated rubber coating that has been designed specifically for use in the nuclear industry where the possibility of contamination by radioactive material exists. I.C.I. showed some of the uses of titanium in chemical plant, for electrolytic cells and for cathodic protection.

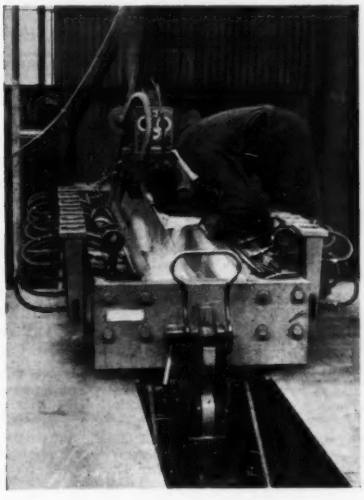
Newalls Insulation report that under their contract with Babcock and Wilcox for insulating the Chapelcross power station, they completed over 300,000 sq ft of vessels and piping requiring insulation.

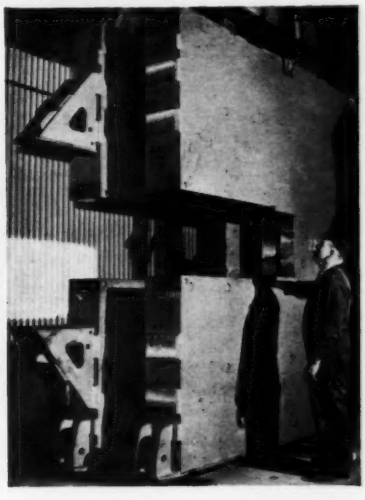
Isotope Developments, Nuclear Engineering and the **AEA** will be exhibiting at the International Congress of Radiology at Munich, July 23-30.

Square D will have a complete range of machine tool control equipment at the 6th European Machine Tool Exhibition in Paris, September 12-21.

A new universal transfer function analyser is announced by **Servo Consultants.**







Three stages in the production of the magnet sections for the 7 GeV proton synchrotron for the National Institute for Research in Nuclear Science, Harwell. The magnet is being built by Joseph Sankey at their Wolverhampton works. (Above) Plate laminations held down by 50 tons of weights while side plates are welded on. (Below, left) Two 5 ft plates being welded together by means of a specially developed jig. (Below, right) Two of the completed 20 ton sectors before final inspection.

President of the Board of Trade, Sir David Eccles, officially opened **Kelvin House** on May 4.

Technograph Printed Circuits and **Technograph Electronic Products** have moved to Eros House, 29 Regent Street, London, S.W.1. Tel.: Regent 5273.

A conference will be held on X-ray diffraction and spectography in conjunction with the department of chemistry at the **Imperial College of Science and Technology,** London, from July 6-10.

James Booth and Co. supplied the hollow copper conductor for the magnet coils of the 7 GeV proton synchrotron.

E. Wilson, sales and service representatives of **Research and Control Instruments,** have changed their address to 35 Hilton Road, Bishopbriggs, Glasgow. Tel.: Bishopbriggs 2320.

Consolidated Electrodynamics have developed a portable gas leak detector capable of recording gas leaks occurring at the rate of 2×10^{-10} atmospheres cm³/sec.

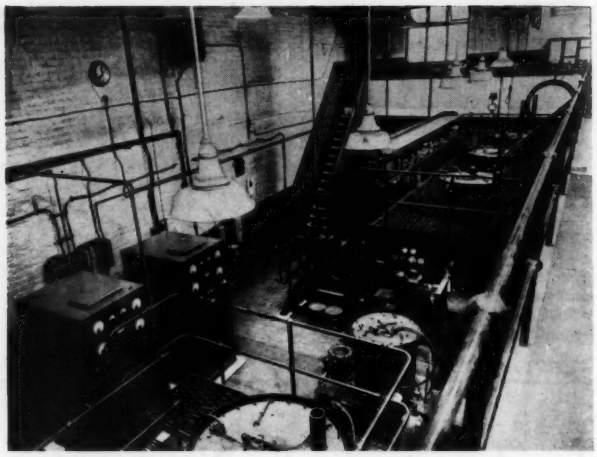
British Insulated Callender's Cables are now applying the principle of mineral insulation to thermocouple production. BICC M.I. thermocouples, which are used in nuclear power stations, are available in lengths of up to 100 yards, with overall diameters as small as 0.060 in.

University Microfilms have moved to 44 Great Queen St., London, W.C.2. Tel.: Holborn 0808.

CEGB report that a reduction in fuel costs last year, equivalent to more than £4½ million, was the result of improved thermal efficiency power stations. The overall average thermal efficiency during the 12 months of 1958 was 25.99 per cent.

International Computors and Tabulators have formed a German subsidiary, **I.C.T. G.m.b.H.,** at Düsseldorf to take over all existing business of **Power-Samas** accounting machines in Germany. They have changed their U.K. address to Gloucester House, 149 Park Lane, London, W.1. Tel.: Hyde Park 8080.

Texas Instruments have formed a Geosciences and Instrumentation division, Dallas, Texas. **Metals and Controls** have recently been merged with the company.



The Metro-Cutanit sintering furnaces of Jessop-Saville for producing cemented carbide cutting tools. A film on the production of cemented carbides was recently shown at the Connaught Rooms, London.

Plessey Maschinen Elemente Gesellschaft is the name of the German subsidiary of **Plessey International,** recently formed at Neuss, near Düsseldorf.

Cooke, Troughton and Simms are to manufacture the Dr. John McArthur microscope and the instrument will be known as the **Cooke-McArthur** microscope.

The responsibility for the issue of import certificates has been transferred to the **Export Licensing Branch,** Gavrelle House, 2 Bunhill Row, London, E.C.1.

The research and development division of **Baird and Tatlock** has recently been doubled in size and two new sections of the division known as Analmatic instruments and general instruments, have been formed.

Vitro Corporation of America have amalgamated the operations of their Vitro Uranium division with those of the Heavy Minerals Co.

Southern Instruments have become associated with the **Ampex Corporation** of America and the U.K. subsidiary, **Ampex Electronics** for the manufacture and marketing of Ampex tape equipment in the U.K.

Rocol opened their new factory and laboratory at Swillington, Leeds, on May 28.

The publicity and accounts departments of **Cambridge Instruments** are again located at 13 Grosvenor Place, London, S.W.1. Tel.: Belgravia 5066.

British Insulated Callender's Cables have changed the telephone number of their Middlesbrough branch to Middlesbrough 3974-5.

Plessey have signed an agreement with **Elettronica Metal Lux,** of Milan, for the manufacture in the U.K. of Metallux resistors. Plessey have been sole U.K. agents for the resistors for 18 months. They will now hold selling rights for the Commonwealth as well. A separate production unit with extensive new equipment will be installed for the manufacture of the resistors at the Kembrey Street factory, near Swindon.

A new company, **ACF (Great Britain),** has been formed as U.K. and European representatives for **ACF Industries.** Offices are located at 55 High Holborn, London, W.C.1. Tel.: Cha 4206.

United Steel showed a preview of their latest film on steel making, "Steel Town," at the Royal Commonwealth Society, London, on May 4. It is the story of what the steel industry—in particular the works of Samuel Fox and Co.—mean to Stockbridge.

Catalogues

The *Simon Magazine*, April issue, has a note on the **Simon-Carves** participation in the building of the Hunterston nuclear power station. (Henry Simon (Holdings), Cheadle Heath, Stockport.)

The **International Panel** have published a summary report of the Italian nuclear power project, ENSI (Energia Nucleare Sud Italia). (International Bank, 1818 H Street, N.W., Washington 25.)

Inco-Mond Magazine 9 contains several interesting articles on metals for valves. (Mond Nickel, Thames House, Millbank, S.W.1.)

The Bulletin of the **"Boris Kidrich" Institute of Nuclear Sciences,** Belgrade, contains a report on the radiation accident to six workers in October, 1958. March edition, Vol. 9. (P.O. Box 522, Belgrade.)

An attractive brochure describes the nuclear engineering activities of **Vickers-Armstrongs (Aircraft),** South Marston works. (P.O. Box 8, Swindon, Wilts.)

A brochure describing the **British Exhibition** to be held in New York June 10-26 1960, has been produced. (British Overseas Fairs, 21 Tothill Street, London, S.W.1.)

The March-April issue of *BTH Activities* contains an article on a new high-speed circuit-breaker. (British Thomson-Houston, Leicester.)

A bound set of friction charts for air flow in straight ducts and pipes has been produced by **Sturtevant Engineering.** (Southern House, Cannon Street, London, E.C.4.)

A booklet, *Steel Foundry Service*, has been published by **North British Steel Foundry** as a reference and service guide to the industry. (157 Victoria Street, London, S.W.1.)

H. T. Watson have published a new catalogue called *Spray Equipment No. 459*. (Croft Street, Widnes, Lancs.)

A description of the part played by **Brockhouse Engineering** in the removal of radioactive fuel elements and apparatus from the DIDO reactor at Harwell is included in the April/June issue of *The Forge*. (24 Hanover Square, London, W.1.)

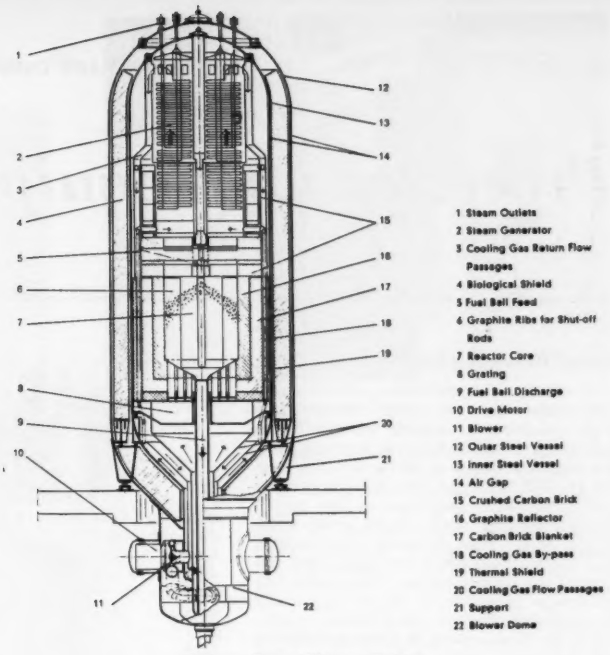
Some aspects of cross wire welding of aluminium alloys and a new gamma-ray therapy unit, the Orbitron, are discussed in the February volume of the *Metropolitan-Vickers Gazette*. (Trafford Park, Manchester.)

The latest issue of *Management Views*, a **Remington Rand** publication, contains details of their new small electronic computer. (Commonwealth House, 1-19 New Oxford Street, London, W.C.1.)

The **General Electric** 1958 annual report contains a section on the company's activities in the nuclear field. (570 Lexington Avenue, New York 22, New York.)

The HANOVER FAIR

Nuclear engineering exhibits at the German Industries' Fair, Hanover, held from April 26 to May 5



Brown Boveri/Krupp Design.

THE most impressive nuclear energy exhibit at this year's Hanover Fair was the 20-ft. model of the high-temperature reactor for which design work has been largely completed by the **Brown Boveri/Krupp** consortium under a development contract for the Arbeitsgemeinschaft Versuchs-Reaktor G.m.b.H. of Düsseldorf.

Situated in the nuclear energy section of the Krupp display, under a red transparent plastic dome, which had the striking effect of illuminating the model with red filtered daylight, the exhibit aroused much interest. In the unorthodox design, the fuel elements will take the form of 6-cm diameter graphite balls each loaded with a pellet of uranium in ceramic form enriched with 20% uranium 235, which fill the reactor core. The heat generated will be carried from the core by a cooling gas composed of helium and neon, which leaves the reactor at approximately 850°C after flowing upward through the pile. It is claimed that the steam generator located at the top of the core will be capable of raising steam at a pressure of 75 kg/cm² and a temperature of 505°C.

Control and safety rods are eliminated by taking advantage of the negative temperature coefficient.

U.K. Exhibition

Britain's lead in the construction of large nuclear power stations was well represented by the **U.K.AEA** stand in Hall 3, sponsored by the Board of Trade. Part of the stand was devoted to a small cinema in which three excellently-presented colour films with German sound-tracks were shown.

The other main feature of the stand was a display of fuel elements manufactured by the U.K. AEA ranging from the earliest in 1947 for the GLEEP reactor with a can temperature of 60°C to the elements now being designed for the advanced gas-cooled reactor at Windscale (600°C) and the O.E.E.C. high temperature gas-cooled reactor (Dragon project: 800-1,000°C) at Winfrith Heath.

German Exhibits

On their large stand in Hall 13, **A.E.G. (Allgemeine Elektricitäts - Gesellschaft)** showed a 1 : 25 scale model of the boiling-water reactor which they, in conjunction with International General Electric of America, and Hochtief AG., are already building at Kahl am Main. This is the first power reactor to be constructed in Germany, though design work on several others is complete, and is a research-power installation of 15 MW output.

In the model, the cylindrical steel outer shell was replaced by Perspex, so that the internal parts could be seen, including reactor pressure vessel, heat exchangers, condenser, feed-water reservoir and pumps, and fuel charging equipment. The reactor will operate at a temperature of 286°C, and will generate live steam at 46.7 kg/cm² (abs.), 258°C, in the secondary heat-exchanger circuit to drive an A.E.G. 16 MW turbine at 3,000 r.p.m. Provision will be made for doubling the output of the reactor by increasing the primary steam flow should initial operating experience prove successful.

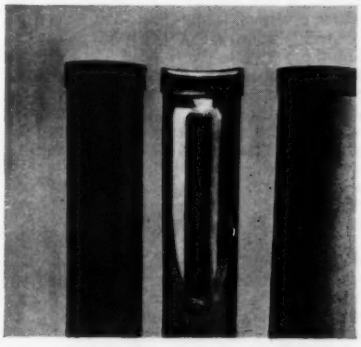
In a showroom made in the form of a hollow aluminium - coloured sphere, **Siemens** had erected one of their exhibits from last year's "Atoms for Peace" exhibition at Geneva. This consisted of a 1 : 5 sectioned scale model of their heavy-water reactor type SNDR designed for power-station use with a net electrical output of 130 MW. A control desk connected to the model together with a small reactor simulator enabled control operations to be initiated and the results represented by changes in intensity coloured illuminations. Rod position and power-level indicating instruments were mounted on the console.

INTERATOM, the international atomic energy company formed by North American Aviation, Inc., and DEMAG AG. of Duisberg, West Germany, showed three nuclear energy models. The first was an organic reactor for propulsion of a nuclear-powered tanker and was based on work which is already in progress under a design contract awarded to INTERATOM by the Gesellschaft für Kernenergieverwertung in Schiffbau und Schiffahrt.

Components and Materials

In addition to the four main German nuclear power consortia and the U.K.AEA, a large number of firms showed components and materials for nuclear plants. Many Canadian mining interests were represented, including **Eldorado Mining and Refining, Algom Uranium Mines, Faraday Uranium Mines** and **Pronto Uranium Mines,** also **Canadian General Electric** and **AMF Atomics (Canada).**

Mannesmann, Gutehoffnungshütte Sterkrade, Kohlenscheidungs - Gesellschaft, Phoenix Rheinrohr and **Aug. Schnakenberg** displayed heat-exchanger tubes, components for reactor pressure vessels, etc.



Fuel element designed by Atomic Power Constructions.

Processes and Equipment

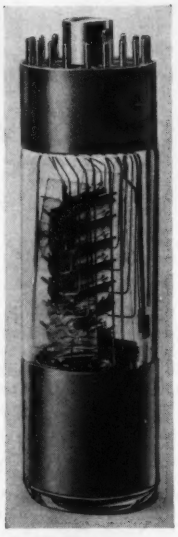
For further information on any item please enter the relevant number on the Reader Service Card enclosed with this issue and forward the card to the address given.

New Photomultiplier

A 14-stage photomultiplier tube designed specifically for use when exceptionally high definition is required in scintillation counting and nuclear radiation spectrography, has been introduced by Mullards. The tube, the 56 AVP, has transit time differences under typical operating conditions as low as 0.3 millimicrosecond which results in the width of the output pulse delivered being as little as 2 millimicroseconds at half height, and rise time of the same duration. This transit time differences reduction is due to a specially designed input electron optical system consisting of the photocathode, a focusing electrode, an accelerator and a deflector plate. The photocathode is curved so that the path lengths to the first multiplier stage are approximately equal for electrons leaving any part of its useful area. The focusing electrode and the accelerator act to concentrate the electrons into a single, narrow path, and to compensate for inequalities in their initial velocities. The deflector plate directs the electrons on to the first of the secondary cathodes. The very narrow pulses obtainable from the tube make it advisable to dispense with an external amplifier and the tube has been designed to provide a peak anode current of 1A.

(Mullard, Ltd., Torrington Place, London, W.C.1.)

1202



The new 14-stage 2-in. dia. photomultiplier tube introduced by Mullards.

Welding Pressure Vessels

With the addition of new radiographic inspection facilities at their Newark works, Farrar Boilerworks are hoping shortly to be approved for Lloyd's Class 1 welding. This is the second item of equipment installed at Newark during the past year. The first was an automatic Fusarc high lift boom welding machine with CO_2 gas shield, which since its installation in February, 1958, has enabled Farrar to upgrade welds on pressure vessels.

The machine comprises a Fusarc automatic welding head and control panel mounted on a 17-ft 6-in. long boom supported at one end by a motorized carriage within a vertical framework. The height can be readily adjusted and the roller bed carrying the vessel to be welded can be controlled by means of push-buttons from the operator's panel. Adjacent to the weld head there is a lay trough, so that the operator can supervise a long seam weld. The unit will carry, traverse and rotate a vessel of up to 12 tons. It is suitable for the internal welding of vessels from 2 ft 6 in. diameter or for the external welding of vessels from 12 in. to 9 ft diameter.

The new X-ray unit is a 150-kV Newton Victor machine with 360° beam tube. The equipment is easily transportable and, since its installation a few months ago, Farrar have been able to increase consistently the standard of weld obtainable.

(The Farrar Boilerworks, Ltd., Newark-on-Trent, Notts.)

1203

Stress-sealed Butterfly Valve

Cockburns of Cardonald have recently secured the exclusive manufacturing rights for Europe of the Rockwell stress-sealed butterfly valve. Some interest has already been shown in this type of valve for inclusion in main CO_2 coolant circuits. A range of sizes is available: an accompanying illustration shows a 60-in. diameter unit.

The valve body of the Cockburn-Rockwell unit makes use of a 7 in. wide alloy band welded peripherally into the body. When the disc is rotated to the closed position, it seats against this band. The final sealing effect is achieved by pressurizing the band with an external source of nitrogen.

Using this sealing technique, there is no need for critical dimensions on the large mating services of the valve disc and body. An additional advantage in this respect is that because of the larger clearances permissible the valve is not so susceptible to corrosion.

The valve body is fabricated from mild, alloy or stainless steel depending on the purpose, and the stress band is usually of high nickel alloy. The disc may be of the same metal as the valve body, but it can be edged with stainless steel. The disc shaft is generally of high tensile steel or stainless steel. Because the shaft is offset the disc has a full 360° sealing surface. Operation can be manual or mechanical and it is possible to incorporate limit switches for controlling and indicating open and closed positions.

(Cockburns, Ltd., Cardonald, Glasgow.)

1204

60-in. bore stress-sealed butterfly valve for main CO_2 coolant circuit (Cockburns Ltd., Clydesdale Engineering Works, Cardonald, Glasgow, S.W.2.)

Ceramic Oxides Display

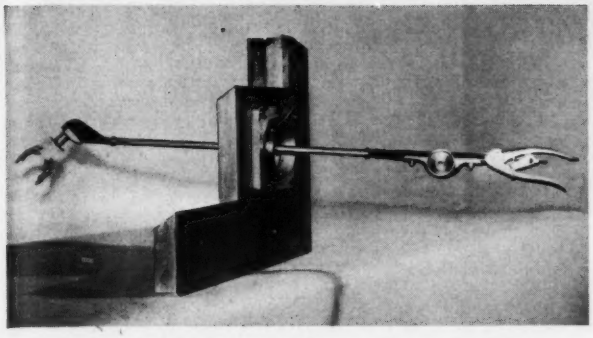
An impressive display of products based on Purox ceramic oxides was recently held in London by Morgan Refractories. Since the company was formed 10 years ago it has made remarkable progress in the development of specialized refractories—an increasing number of which are now being used in nuclear engineering.

For reactor applications Forsterite, Gadolina/alumina, Samaria/alumina and Samaria/magnesia offer considerable scope for development. Forsterite has a thermal conductivity as low as that of zirconia together with a very low neutron absorption. Gadolina/alumina and Samaria/alumina could replace boron-steel as control-rod material. Purox pure magnesia ware (containing not less than 98% MgO) can be used for thermal barrier discs in fuel elements or as crucibles for melting uranium.

Purox recrystallized alumina (containing not less than 99.7% Al_2O_3), is believed to be the purest alumina available on a commercial scale. Typical applications include sheaths for platinum/rhodium thermocouples, insulators and high-temperature furnace tubes. Amongst some of the unusual components in this section of the display were parts of a fuel element grab developed for one of the commercial consortia. Purox thoria products (not less than 99.9% ThO_2) included both impervious and standard forms. Crucibles in this material may be used for melting uranium and zirconium, titanium and hafnium. Morgans have already supplied a quantity of thoria for use in a breeder reactor.

(Morgan Refractories, Ltd., Neston, Wirral, Cheshire.)

1205



The new T5 manipulator by Nuclear Research Applications can be removed from the shielding wall and the cavity closed by a plug.

Versatile Manipulators

The EMEFCO T4 manipulator with remotely controlled rotating head and ratchet-type holdfast device in the operator's handgrip is extensively used in nuclear establishments throughout the world. Originally made in lengths of up to 6 ft, standard sizes of 8 ft., 10 ft and 14 ft have recently been added.

The head of the T4 rotates 370° and the claws are sufficiently sensitive to pick up a needle just as easily as a beaker or isotope capsule. To prevent glassware being crushed the pressure on the jaws is automatically limited to a pre-determined figure, irrespective of the strength applied to the handgrip.

Because of the demand for a tool which could be operated through a lead wall, Nuclear Research Applications have recently introduced the T5. The shaft is pivoted in a universal ball joint comprising a special split sphere machined in such a manner that concentric ridges in the sphere form an effective joint and barrier against radiation. The sphere is accommodated in a cavity of specially constructed 2-in. thick lead brick with the usual 34° interlocking vee edges, the cavity being constructed in such a manner that approximately 90° angular movement in all directions can be achieved.

The sphere itself is located by means of a pressure cone having axial movement to the shaft: a rotating locking ring allows the pressure cone to be moved slightly forwards and backwards so that the sphere can be freely rotated or locked at any angle. A separate mechanism enables the operator to lock the axial position of the shaft.

The advantage of this arrangement compared with conventional forms of manipulators is not only that the tool can be locked in any position and at any angle but that improved operation is possible because of the 370° rotating head and the 45° offset angle of the tool. Furthermore the complete tool, sphere and locking plate can be easily removed and the cavity closed.

(Nuclear Research Applications, Ltd., Emefco House, Bell Street, Reigate, Surrey.)

1207

Steam Stop Valve

A new control stop valve for use in steam lines is being introduced by Sir W. H. Bailey and Co. Known as the Bi-Seat, the precision-made unit is of a unique design which, it is claimed, affords an extremely high degree of control and double protection of the working parts. It is designed for controlling a flow of steam at working pressures of up to 300 p.s.i. and temperatures as high as 500°F.

On initial opening, the main valve is raised approximately $\frac{1}{16}$-in. clear of its flat seat, but the orifice remains sealed by a special spring-loaded parabolic plug. As the unit is opened more fully, the plug is gradually withdrawn from the orifice to provide a streamlined annulus for the passage of steam. This design makes it virtually impossible for foreign matter to be trapped on the main valve seat, and the fine degree of control—from minimum flow to full bore—allows steam to be admitted slowly to a cold system with full protection for the valve and seat against the direct cutting action of the high-velocity steam, thus preventing wire drawing.

The same high degree of protection is afforded to the seat when the control valve is being closed, because the steam is shut-off by the parabolic plug before the main valve comes into close contact with it. All working parts are made of " K Monel " and stainless steel to ensure a long and trouble-free life.

(Sir W. H. Bailey and Co., Ltd., Albion Works, Patricroft, Manchester.)

1206

Overwall Tong

Teleflex Products, who have a wide experience of remote handling problems, have recently introduced an overwall tong, for the remote manipulation of radioactive and toxic materials. The unit obviates the necessity for remote handling at fixed stations, is sealed and does not require maintenance. It can be used for gripping, carrying and rotating, and because it is virtually free from back-lash, is sensitive and positive in action. It was designed in conjunction with AERE, Harwell.

The control mechanism comprises a unique flexible shaft, one end attached to an operating mechanism, and the other to a tong head. The tong head—of standard AERE design—is closed by a trigger mechanism with a fine adjustment for positive grip; it is rotated by means of a twist grip handle. A quick release trigger provides instantaneous release of the tong grip.

The body of the unit has an engraved scale of three markings, adjacent to the adjusting sleeve. Maximum and minimum fine adjustments of the tongs are indicated by red marks, and the intermediate position by a white mark. The support handle is adjustable for position and readily adapted to suit right- or left-hand operation. A hook is provided for storage and also for the attachment of a pulley wire and counterweight if required. The weight of the unit with the tongs—which are completely interchangeable—is 6¾ lb, without tongs 6 lb.

(Teleflex Products, Ltd., Basildon, Essex.)

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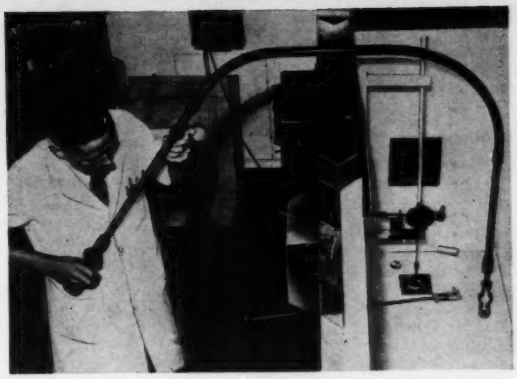

Overwall tong developed by Teleflex Products of Basildon.

Fast Neutron Meter

A high-sensitivity fast neutron survey meter, model FN2B for the detection and measurement of fast neutrons in the presence of intense gamma radiation fields is now being offered by Nucleonic Corp. of America. The detector consists of a uniform dispersion of zinc sulphide (ZnS) grains moulded directly into lucite. The lucite serves the dual purpose of supplying the proton recoils which produces the light scintillation in the phosphor and of transmitting this light to the photomultiplier tube. Operation is unaffected by gamma rays from Cobalt-60 up to 4rh. It has no sensitivity to slow neutrons.

Neutron flux measured in neutrons/cm², sec. is read on a panel meter. A switch with 3 ranges of sensitivity; 0-5, 0-50, and 0-500 neutrons/cm²,sec. permits easy range adjustment. The three ranges are linear and require no calibrating chart. On the most sensitive range, 5 neutrons/cm²,sec. gives full-scale deflection. Since tolerance dose for fast neutrons is 20 neutrons/cm²,sec. the instrument gives full-scale deflection for 1/4 tolerance dosage.

(Nucleonic Corporation of America, 196 Degraw Street, Brooklyn 31, New York.)

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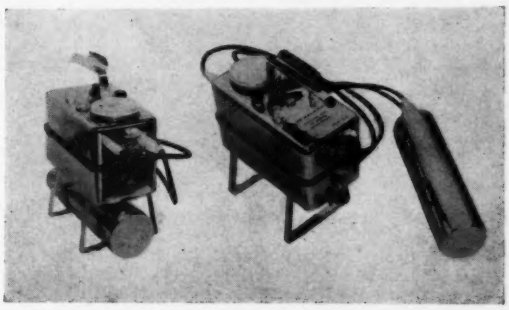

High sensitivity fast neutron survey meter, model FN2B.

Patents Reviewed

These abstracts have been made from British Patent Specifications, complete copies of which can be obtained from the Patent Office, 25 Southampton Street, London, W.C.2, at 3s. 6d. each (including postage).

B.P. 802,971. Process for the destruction of radioactive residues. L. Verschraeghen (Belgium).

The residual material is exposed to radiation, such as nuclear particles, as a result of which, long-life radioactive constituents are transformed into either stable isotopes or short-life radio-isotopes. After irradiation these isotopes are separated from the remainder by fractionation. Should the remainder still show too high a radioactivity, the material is added to a fresh batch, to be treated and processed a second time. Various methods of processing are described. In the case of a homogeneous reactor, the residue material may be placed in special conduits in the interior of the reactor or, alternatively, if available in the form of gases, liquids or solutions, it may be added to the radioactive material passing through the homogeneous reactor; if available in solid form, it may be incorporated in the control rods. In the case of a heterogeneous reactor, the material to be treated may be placed in recesses of the fuel bars or, where slow neutrons are used, in the body of the graphite moderator.

B.P. 802,998. Sheathed annular bodies. L. M. Wyatt and U.K. Atomic Energy Authority.

Conventional fuel element assemblies designed for fuel available in tubular form provide for the inner and outer sheath to be joined and sealed by end rings, welded to both sheaths. In order to reduce the number of welds required to seal the elements it is proposed to employ sheaths flanged at one end, the inner sheath to have an outwardly directed flange and the outer sheath an inwardly directed flange. The sheaths are assembled with their flanges at opposite ends. This reduces the number of welds required to two. Where uranium enriched in U^{235} is used as fuel, stainless steel is recommended as material for the sheaths.

B.P. 803,118. Ternary alloys of uranium, columbium and zirconium. F. G. Foote.

It is reported that uranium metal cast in the high temperature gamma phase (1,000°C) has greater resistance to corrosion by oxidation than in any other phase. This is important when using ternary alloys of uranium as neutron-reflecting materials in a fast neutron pile. Uranium metal becomes stabilized in the gamma phase when closely alloyed with minor amounts of columbium and zirconium in combination (2 to 8%).

B.P. 803,258. Production of uranium halides. U.K. Atomic Energy Authority (U.S.A.)

Uranium tetrafluoride is prepared from the oxide U_3O_8 by maintaining the oxide in particle form in fluidized suspension at elevated temperature in hydrogen to convert it to uranium dioxide. Uranium tetrahalide is then produced by the interaction of a gaseous hydrogen halide and the uranium dioxide at elevated temperature maintained in fluidized suspension in the hydrogen halide.

B.P. 803,264. Extraction of metals from aqueous solution. N. F. Kember and U.K. Atomic Energy Authority.

Thorium, uranium, zirconium and hafnium are extracted by an adsorption method based on the observation that these metals are strongly adsorbed from aqueous mineral acid solution by phosphorylated cellulose. The aqueous solution containing the metals should have a concentration at least N10 with respect to mineral acid.

B.P. 803,274. Process for the production of water or hydrogen having an increased deuterium content. E. W. A. Becker (Germany).

Hydrogen and water are passed in counter-current, at elevated pressure (100 atm) and in the presence of a catalyst through two columns, a lower and an upper column, maintained at different temperatures. The water passes first through the cold column (20-50°C) and then through the hot column (about 200°C) whereas the hydrogen passes first through the hot column and then through the cold column. The cold column serves as a concentration column. The catalyst is preferably a platinum or palladium sol in the water circulating through the columns. The deuterium-enriched product may be continuously withdrawn in various ways.

B.P. 803,382. Vapour generators. W. R. Wootton and Babcock and Wilcox, Ltd.

Normally, the general layout of a nuclear power station employing a gas-cooled reactor as the primary heat source provides for the reactor proper to be housed in a building unit of its own and the vessels containing the heat exchangers to be situated externally, connected with the reactor shell by ducting for the circulation of the coolant. This arrangement has various drawbacks: the area occupied by the vapour generating section of the power station is considerable, erection costs are high because of the variety of buildings and structures required, and the interconnecting ducting must allow for thermal expansion and contraction as they occur in service, without involving the risk of leakages. A saving in initial cost can be effected by placing the reactor, the circuit for the gaseous coolant and the heat exchangers within a common pressure vessel. In one embodiment of the invention, the pressure vessel is cylindrical, positioned vertically and its bottom portion, which is of a large diameter, houses the reactor. This part of the pressure vessel is surrounded by a biological shield of concrete. In addition, the space within the upper portion of the pressure vessel is protected by an internal, horizontally placed, biological shield. The latter part of the pressure vessel projects beyond the outer biological shield and houses the heat exchangers. The coolant is circulated by means of built-in fans along a well defined path within the pressure vessel. The second embodiment represents an arrangement based on the same principles designed to suit a pressure vessel of spherical shape.

B.P. 803,569. Nuclear reactor plant. Stichting Reactor Centrum Nederland (Netherlands).

It has been proposed to enclose a reactor and any other parts of the plant where leakage and scattering of radioactive materials could occur in a common shell strong enough to resist all pressures in the case of plant failure. This shell would have to be very large even for a small nuclear reactor; in one existing plant a spherical steel shell of a diameter of 65 m is employed. A simple solution of the problem would be the provision of a shell enclosing the reactor and associated apparatus, connected to an expansible gas-holder situated outside. Then, in the event of an undue rise of pressure the gas would flow to, and collect in, the gas-holder. The gas-holder should preferably be of the wet gasometer type in order to facilitate condensation of the gases and vapours. Costly liquid (heavy water) may thus be recovered from the condenser.

B.P. 803,689. Process for separating gaseous or vaporous substances, more especially isotopes. Deutsche Gold-und Silber-Scheideanstalt vorm. Roessler (Germany).

Reference is made to B.P. 794,834 which describes a process of separating gaseous or vaporous substances of different molecular weight and/or molecular diameter, in particular isotopes. The separating system consists of a nozzle and an apertured diaphragm which is placed in the path of the jet, formed by the mixture when passing through the nozzle, and dividing the jet into a core stream and a peripheral stream, the heavier and lighter components of the mixture thus being concentrated in the respective component streams. In order to obtain good quality separation, it is important to maintain a specific ratio of the pressure of the gas entering the nozzle to the pressure of the gas leaving the nozzle, this ratio varying from 100 : 1 to 1,000 : 1. In the previously described form of the process, suitably designed pumps were employed for maintaining these pressure ratios with delivery of the streams of vapour or gas. Where the method is employed in the form of a multi-stage process, a plurality of pumps with high capacities is required making the equipment expensive. In the present patent a revised version of the method is described, eliminating the use of pumps for this purpose. Instead, the transport of the gases and vapours through the separating system is effected by successive vaporization and condensation steps, resulting from periodical addition and withdrawal of heat. The process being carried out in the sub-atmospheric pressure range can also be used for subliming substances, e.g., for the concentration of uranium isotopes from uranium hexafluoride.

B.P. 803,708. Nuclear reactor control mechanism. R. G. Noakes, C. D. Boadle and Rolls-Royce, Ltd.

In nuclear reactors of the solid-moderator type a considerable amount of space is required solely for the purpose of accommodating the conventional control rod arrangement. In order to economize in space it is proposed to use control elements of part-cylindical form, the size of a quadrant for instance, which are mounted in the reflector body in an upright position and can be rotated by means such as a spindle around their (vertical cylinder) axis in a path specially cut into the reflector mass. Thus, in action, the cylinder section forming the control element (and made from material of high neutron absorbing capacity such as cadmium or boron) would be in a position between the reflector body and core, intercepting neutrons before they can reach the reflector mass, whereas when not in use, the element would be positioned between reflector body and pressure vessel wall, permitting the respective area of the reflector mass to function normally.